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Characterization and Comparison of Wet Milling Fractions of Export Commodity Corn Originating from Different International Geographical Locations

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Soft endosperm corn has evident characteristics suitable for wet milling but is susceptible to breakage and fracture during transportation. In this study the millability of commodity corn samples with different endosperm hardness originating from different international locations is compared, and its economic impact on corn importers for wet milling is discussed. The broken corn and foreign material (BCFM) for the soft endosperm US commodity corn ranges from 1.13% to 5.57% which is higher than other commodity corn from other international locations exported to the same country. US corn exported to different international markets shows higher starch yield in a range of 5–8% compared to the corn from different geographical locations exported to the same market. The excess starch from US corn directly translates to an additional revenue of 8.13–13 million USD per year for a 2540 MT day^{-1} wet mill plant. Therefore, it can be concluded that the soft endosperm US commodity corn, despite higher breakage, has superior millability and gives higher starch yields compared to the hard endosperm corn from other international locations which has comparatively lower BCFM. There are technologies that can be used to process broken corn separately after the initial cleaning process.

1. Introduction

The typical corn kernel (*Zea mays* L.) consists of starch, protein, fat, sugars, and crude fibers. Corn wet milling leads to the fractionation of these components and generation of valuable products such as starch, glucose and dextrose, high fructose corn syrup, etc., and the coproducts such as corn gluten meal, corn gluten feed, and germ.[1] Starch and starch hydrolysates are the major product of wet milling and are utilized primarily in the food and beverage, fuel alcohol, and industrial biotech segments.

In the year 2021, around 164 million tons of corn were processed for food, alcohol, and industrial use by wet milling out of the total 358 million metric tons produced in the United States of America.[2,3] During the same period (2020–2021), the United States exported 69.8 million tons of corn worth 18.63 billion USD to countries like China, Egypt, Taiwan, South Korea, Colombia, Indonesia, Saudi Arabia, etc. a major portion of which is utilized for wet milling.[4] Wet mill starch yield is the significant factor contributing to the cost-effectiveness for end-users of this corn. However, a major concern for wet millers is broken corn and foreign material (BCFM) in the shipments. The BCFM and other changes in the corn quality are caused by long-distance transport, which involves several handling steps like mixing, storing, loading and unloading, and transferring.[5] The changes in corn quality result in economic loss for the grain providers and the end-users. The corn available in different international markets is produced under different agronomic and climatic conditions and has genetic variations, resulting in differences in physical properties, endosperm hardness and wet milling characteristics. Corn endosperm hardness significantly affects starch extractability in wet milling. The hardness of endosperm is related to endosperm structure, composition, structure of granules, and protein distribution. The greater hardness leads to the desirable qualities for storage, handling, and transport; however, it is adversely related with starch extractability.[6] For yielding higher starch the US corn has been bred for decades, resulting in higher starch extractability. However, due to the US midwestern weather, there is a short harvest window for the US corn, thus, the harvest moisture content is typically higher than 13%. For prolonged storage and export of corn, there is a requirement for artificial drying, which leads to stress cracks.[7,8] Therefore, the US commodity corn, generally having softer endosperm, is susceptible to breakage due to stress cracks during transport and shipping consignments to international locations.[5,9] On the other hand, the corn originating in other regions, e.g., South American corn,

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generally has hard endosperm and is field dried prior to harvest and does not have stress cracks.

Corn wet millers import commodity corn from United States, South America, and other geographies; however, due to the higher amount dust and BCFM, the US commodity corn is considered inferior compared to other commodity corn from South American, which is most suitable for storage and transport and has less dust and BCFM.[9] Broken corn and dust cause problems in steeping such as blurred screens in steep tanks, channeling of steepwater (resulting in inadequate steeping), and an increase in solubles in steep water. Wet millers thus face issues in handling broken corn and dust and an additional effort is required for cleaning it.[10] To avoid processing issues, broken corn after cleaning is often mixed with corn gluten feed (CGF) directly thus bypassing the steeping and milling process and resulting in loss of starch in CGF and lower overall starch yields. Because of these reasons, US corn is not preferred by some international importers of corn for wet milling where the corn consignments are approved based on physical quality of the corn. Nonetheless, the economic feasibility of the wet milling process depends largely on wet mill starch yield, and hence the wet milling characteristics of corn should be assessed. Every percent increase in starch yield over a year can result in substantial additional revenue for a corn wet milling plant. Therefore, the wet mill yields, primarily the starch yield, should be the primary basis for choosing corn for wet milling and not the physical characteristics. The wet milling characteristics of different commodity corn samples can be determined by laboratory wet milling studies.[11] This study is in succession with a previous study from our group which presented the assessment of the millability of USA and South American (Brazil and Argentina) commodity corn collected from different geographical locations (Colombia, Taiwan, and Tunisia) in the year 2019.[12] The present study involves the assessment of the millability of the corn harvested in the year 2020 to assess the variations in the wet milling characteristics compared to the previous crop year and includes three additional origin locations (Ukraine, Serbia, and Indonesia) and four additional collection locations viz. Egypt, South Korea, Indonesia, and Saudi Arabia along with Taiwan and Colombia.

2. Results and Discussion

2.1. Wet Mill Starch Yield

Corn processors consider the starch yield in wet milling a most significant factor. The 100 g laboratory wet milling of corn samples grown in different geographical locations (different origins) and collected from different parts of the world show that the starch yield in wet milling ranged from 61.61% to 68.11% w/w, whereas only for US commodity corn samples, it was in a range of 66.64% to 69.11% w/w (**Figure 1**a). The average of starch yields from corn of a particular origin has been depicted in Figure 1b. It is evident from the starch content and starch yield data that despite having similar percentage of starch content (ranged from 70.57% to 72.60%) (**Table 1**) in all the corn samples the starch yield in wet milling varied 61.61–69.11%. This outcome shows that the millability of the corn samples does not depend on the starch content but on the genetics, agronomic conditions, and postharvest practices.[5,13] Higher starch yields from the US commodity corn samples are indicative of the higher millability of soft endosperm corn exported from the United States.

2.2. Physical Properties of Corn Samples

The floatation index, broken corn, (BCFM), as well as test weight are the physical properties that were assessed for all the corn samples. Floatation index is an indicator of kernel density and thus signifies the endosperm hardness. All the US corn samples show a floatation index in a range of 87.33–99.00%, which is higher than the other corn samples (ranged from 21.33–72.33%), however, the floatation indices for EGY (UKR) (98.33%) and KOR (SRB) (95.67%) were comparable with the floatation indices for the US corn. The larger variations (21.33–99.00%) in the floatation indices indicated the differences in endosperm hardness (**Table 2**). The endosperm hardness helps in determining the kernel breakage susceptibility which is a function of the softness of endosperm.[9] Thus, the corn samples with higher floatation indices show higher breakage susceptibility, which is further validated by correlation study with the BCFM values of the samples(**Figure 2**a). However, the artificial drying at high temperatures is also a factor that can contribute to a greater number of floaters due to the stress cracks created because of the greater and sudden moisture loss.[7,14] The BCFM, the US commodity corn, was higher (ranged from 1.13% to 5.57%) as compared to the BCFM (ranged from 0.33% to 3.33%) of other corn samples from different origins (Table 2). Moreover, the US corn showed a comparatively lower test weight (56.12–58.07 lb bu^{-1}) than the test weight (ranged from 54.52 to 60.23 lb bu^{-1}) for other corn samples. Test weight is a function of kernel density as well, and other factors like moisture content, shape, BCFM, artificial drying, and handling also affect the packaging and weight of a bushel of corn.[15]

The observed physical properties (floatation indices, BCFM, and test weights) of different corn samples when compared to the wet mill starch yield show a remarkable trend. Even though US corn has low density and is prone to stress cracks and breakage, it shows a higher starch yield compared to the corn samples from other locations (Figure 1). Moreover, since it is evident from the results that the US commodity corn has the softer endosperm compared to the commodity corn from the other countries, it can be stated that the hardness of the endosperm is negatively correlated to the starch yield and thus millability of the corn. These observations were validated further by performing correlation studies between average wet mill starch yield and average floatation index, BCFM, and test weights for the corn samples of a particular origin (whereas collected from different geographical locations) (Figure 2b–d). The similar observations were found in another study where the millability of US commodity corn was compared with the commodity corn from the different international geographical locations.[12] Therefore, it can be stated that the physical characteristics of the corn do not reflect its millability and thus the starch yield can be determined thoroughly by performing the laboratory wet milling.

2.3. Wet Milling Fraction Yields

The yields of other wet mill components viz. germ, gluten, fiber, and steep water were also determined (**Figures 3–6**). The total

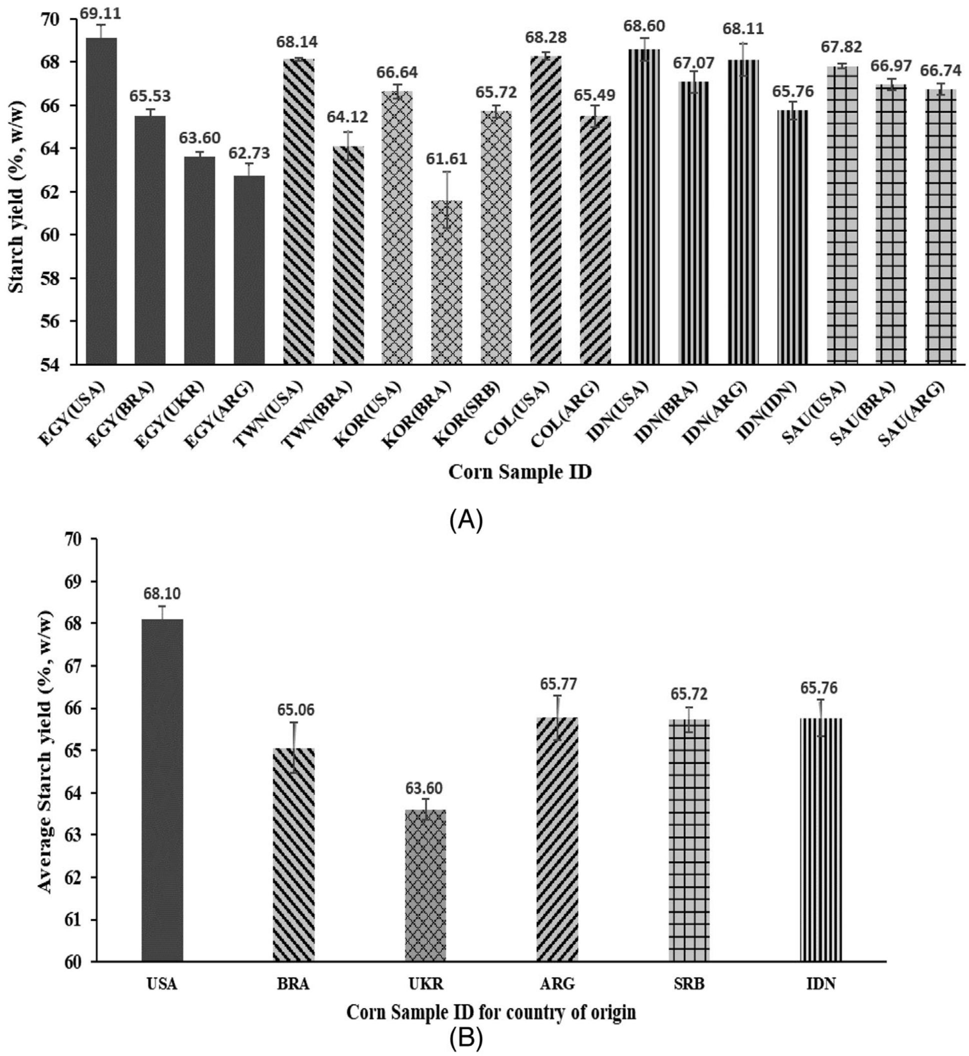

Figure 1. Wet mill starch yield comparison of commodity corn. a) Starch yield (%, w/w) of individual samples. b) Average starch yield (%, w/w) of the samples from a particular origin. Corn sample IDs represent the corn exported from the United States of America (USA), Brazil (BRA), Ukraine (UKR), Argentina (ARG), Serbia (SRB) to the countries of export Egypt (EGY), Taiwan (TWN), South Korea (KOR), Colombia (COL), Indonesia (IDN), and Saudi Arabia (SAU).

Table 1. Chemical composition of export corn.

	EGY USA	EGY Brazil	EGY Ukraine	EGY Argen-tina	TWN USA	TWN Brazil	KOR USA	KOR Brazil	KOR Serbia	COL USA	COL Argen-tina	IDN USA	IDN Brazil	IDN Argen-tina	IDN Indon-esia	SAU USA	SAU Brazil	SAU Argen-tina
Moisture [%][a)]	14.13 ± 0.05	12.50 ± 0.00	13.13 ± 0.05	13.03 ± 0.05	14.27 ± 0.12	12.57 ± 0.05	13.90 ± 0.16	12.80 ± 0.00	12.67 ± 0.05	14.27 ± 0.05	12.97 ± 0.05	14.17 ± 0.05	13.13 ± 0.05	13.50 ± 0.00	13.03 ± 0.09	12.80 ± 0.00	12.97 ± 0.05	13.47 ± 0.33
Starch [%][a)]	71.60 ± 0.43	71.43 ± 0.09	71.07 ± 0.09	71.83 ± 0.25	71.93 ± 0.33	71.53 ± 0.12	72.10 ± 0.29	72.00 ± 0.29	72.00 ± 0.28	72.60 ± 0.37	71.47 ± 0.05	72.00 ± 0.24	72.07 ± 0.34	72.07 ± 0.12	70.57 ± 0.12	72.20 ± 0.29	71.47 ± 0.25	71.60 ± 0.00
Oil [%][a)]	4.00 ± 0.08	4.43 ± 0.05	3.63 ± 0.05	4.23 ± 0.05	3.80 ± 0.08	4.33 ± 0.05	3.90 ± 0.14	4.43 ± 0.05	3.60 ± 0.16	3.83 ± 0.05	4.30 ± 0.08	3.90 ± 0.08	4.13 ± 0.05	4.07 ± 0.09	4.80 ± 0.08	3.97 ± 0.12	4.37 ± 0.12	4.43 ± 0.09
Protein [%][a)]	8.53 ± 0.12	8.87 ± 0.12	9.57 ± 0.05	8.50 ± 0.16	8.23 ± 0.21	8.90 ± 0.08	7.77 ± 0.09	8.43 ± 0.12	8.60 ± 0.08	8.10 ± 0.08	8.87 ± 0.09	8.40 ± 0.16	8.63 ± 0.34	8.47 ± 0.05	9.00 ± 0.28	8.23 ± 0.05	8.73 ± 0.09	8.57 ± 0.12

Corn exported from the United States of America, Brazil, Ukraine, Argentina, and Serbia to countries of export Egypt (EGY); Taiwan (TWN); South Korea (KOR); Colombia (COL); Indonesia (IDN); Saudi Arabia (SAU). All experimental values are mean ± SD ($n = 3$). [a)] Dry basis.

Table 2. Physical properties of commodity corn.

	EGY USA	EGY Brazil	EGY Ukraine	EGY Argentina	TWN USA	TWN Brazil	KOR USA	KOR Brazil	KOR Serbia	COL USA	COL Argentina	IDN USA	IDN Brazil	IDN Argentina	IDN Indonesia	SAU USA	SAU Brazil	SAU Argentina
Floatation index	88.33 ± 2.05	59.67 ± 0.08	98.33 ± 0.47	66.00 ± 7.48	99.00 ± 0.82	43.33 ± 1.25	96.33 ± 1.26	50.33 ± 1.25	95.67 ± 1.70	90.00 ± 1.41	56.33 ± 2.05	94.00 ± 1.63	66.67 ± 2.36	72.33 ± 3.40	45.67 ± 0.94	87.33 ± 3.30	22.00 ± 2.45	21.33 ± 3.4
BCFM [%]	1.9 ± 0.29	0.33 ± 0.09	2.37 ± 0.41	0.57 ± 0.31	2.9 ± 0.92	1.3 ± 0.14	5.57 ± 3.04	0.77 ± 0.17	3.33 ± 2.88	1.13 ± 0.49	0.87 ± 0.17	1.97 ± 0.74	0.63 ± 0.12	1.63 ± 0.09	0.37 ± 0.12	1.50 ± 0.75	2.93 ± 1.95	2.4 ± 0.94
Test weight [lb bu^{-1}]	56.81 ± 0.29	59.67 ± 0.08	54.52 ± 0.11	58.25 ± 0.10	56.12 ± 0.13	60.23 ± 0.19	57.70 ± 0.17	60.15 ± 0.14	57.46 ± 0.17	56.53 ± 0.29	59.20 ± 0.17	57.54 ± 0.03	59.09 ± 0.14	58.95 ± 0.00	57.43 ± 0.22	58.07 ± 0.08	59.74 ± 0.18	59.29 ± 0.80

Corn exported from the United States of America, Brazil, Ukraine, Argentina, and Serbia to countries of export Egypt (EGY); Taiwan (TWN); South Korea (KOR); Colombia (COL); Indonesia (IDN); Saudi Arabia (SAU). All experimental values are mean ± SD ($n = 3$).

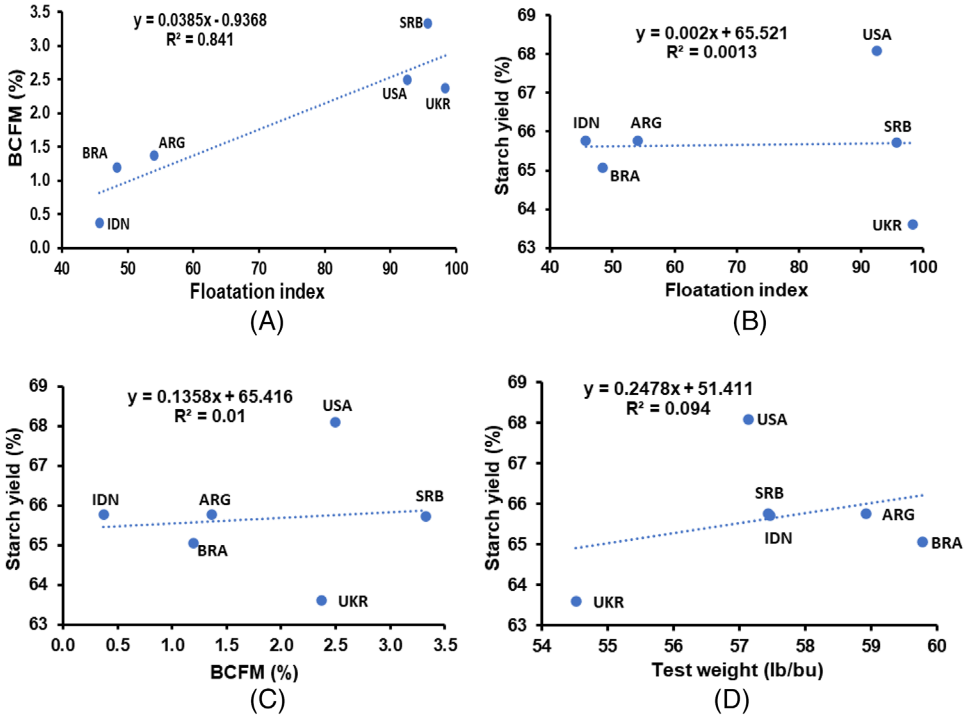

Figure 2. Correlation plots between (a) average floatation index and average BCFM (b) average wet milling starch yield and average floatation index (c) average wet milling starch yield and average BCFM (b) average wet milling starch yield and average test weight of corn samples from the different origins. The Corn sample ID denoted by IDN, BRA, ARG, USA, UKR, and SRB indicate that the parameter values are the average of corn from same origin, Indonesia, Brazil, Argentina, United States of America, Ukraine and Serbia, respectively, which were collected from various geographical locations.

solid recovery in the wet milling was in a range of 97–99% for different corn samples. The oil content in the germ obtained from wet milling was estimated, as well as the protein from the gluten was also recovered and compared. Percentage recovery recorded was in good agreement with the earlier studies carried out with 100 g scale laboratory wet milling.[12,16] The germ recovered was ground and analyzed for oil content which was found to be in a range of 29.96–50.00% by weight on a dry basis. The germ contributed to around 3–6% of the total solids recovered. Germ recovery was highest (6.06%) for COL (ARG) followed by TWN (BRA), and KOR (USA), KOR (BRA), and KOR (SRB), germ recovery was about 5.50% from all these samples. For the remaining samples, the germ recovery was in a range of 3.79–5.33%. There was no significant difference in the germ recoveries, however, the higher germ recovery was corroborated with the soft endosperm corn, this outcome is consistent with the findings in previous studies.[12,17] The recovered gluten was around 4.01–6.52% w/w of the total corn undergoing wet milling. Soft endosperm corn is expected to give lower gluten yield compared to hard endosperm corn. The protein content in the gluten recovered after tabling was approximately 45% on dry basis for most of the corn samples investigated; however, it varied in a broad range of 33.16–53.33% for all corn samples. The coarse fiber and fine fiber fractions, which were combined, formed a major portion of the recovered material and were significantly lower for the US corn (ranged from 13.68% to 16.29%) compared to the other

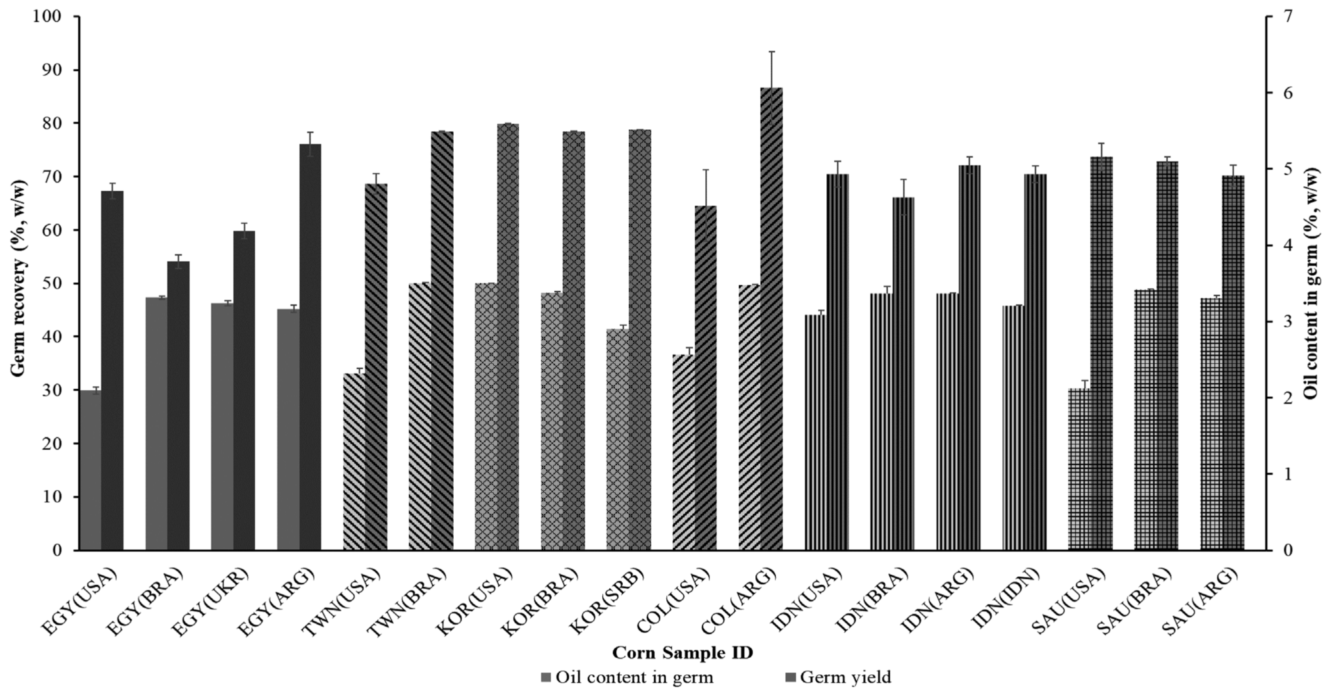

Figure 3. Wet mill germ recovery and germ-oil content comparison. Corn sample IDs represent the corn exported from the United States of America (USA), Brazil (BRA), Ukraine (UKR), Argentina (ARG), Serbia (SRB) to the countries of export Egypt (EGY), Taiwan (TWN), South Korea (KOR), Colombia (COL), Indonesia (IDN), and Saudi Arabia (SAU).

corn samples (14.91–18.65% w/w). This can be attributed to the unrecovered starch, in hard endosperm samples with lower millability, adding to the mass of the fiber, and thus enhanced fiber fraction.

The remaining material separated was made up by the recovered steep water solids. According to prior investigation on BCFM and steep water characteristics, soft endosperm corn dried at higher temperatures is likely to release higher soluble solids and proteins into the steep water.[18] The similar observations were recorded in the present study where the gluten recovery is significantly lower for most of the soft endosperm corn samples, i.e., US commodity corn and the steepwater solids are slightly higher for these corn samples.

2.4. Economic Impact and Technologies for Processing of Broken Corn

It is evident from the results in this study that US commodity corn has comparatively higher starch yield and thus better millability than the corn from other geographical locations. Every 1% enhancement of extracted starch yield from wet milling, repays around 4–6 cents per bushel depending on the sales price of product and plant capacity.[19] The US commodity corn has the 5–8% higher starch yield compared to other corn samples, thus the increase in value for using the US corn for a large-scale wet milling plant can be enormous. These higher starch yields can be realized by separately processing broken corn after cleaning using technologies such as Enzymatic Wet Milling (E-Milling)[20–23] or Intermittent Milling and Dynamic Steeping (IMDS).[24–27] Broken corn can be separately steeped for a short period of time using proteolytic enzyme in E-Milling process or with sulfurous water in IMDS process. After a short steeping the ground broken corn can be mixed with corn slurry from the main process (with whole kernels). Separate processing of broken corn will avoid the processing issues related to blinding of steepwater tanks screens, channeling of water in steep tanks, and loss of solubles in steepwater but at the same time will allow recovery of starch in broken corn. For a wet milling processing plant with a capacity of 100 000 bushels per day operating for 330 days a year, an increase in starch yield by 1% will lead to the increase in revenue by 1.65 million USD.[28] The 5–8% higher starch yield with US corn than other corn samples infers that a wet milling plant operating with US corn as raw material will provide an additional revenue of 8.13–13 million USD per year. Moreover, the economic return will also depend on wet milling efficiency and starch recovery. Since the US corn is a soft endosperm corn, the additional unit operations will be required to remove BCFM for separate processing and better handling during transportation to minimize breakage, however, the cost of adding these extra unit operations can be justified by the higher revenue from higher starch yields. Consequently, for wet milling corn importers the US commodity corn offers enhanced value proposition than the corn from other origins.

3. Conclusion

The starch yield essentially 66–69% from the US corn can lead to higher revenue in wet milling when compared to corn imported from other international locations. The floury texture of the starch yielded from the soft endosperm corn, i.e., US corn in this study, makes it preferred for wet milling over the other

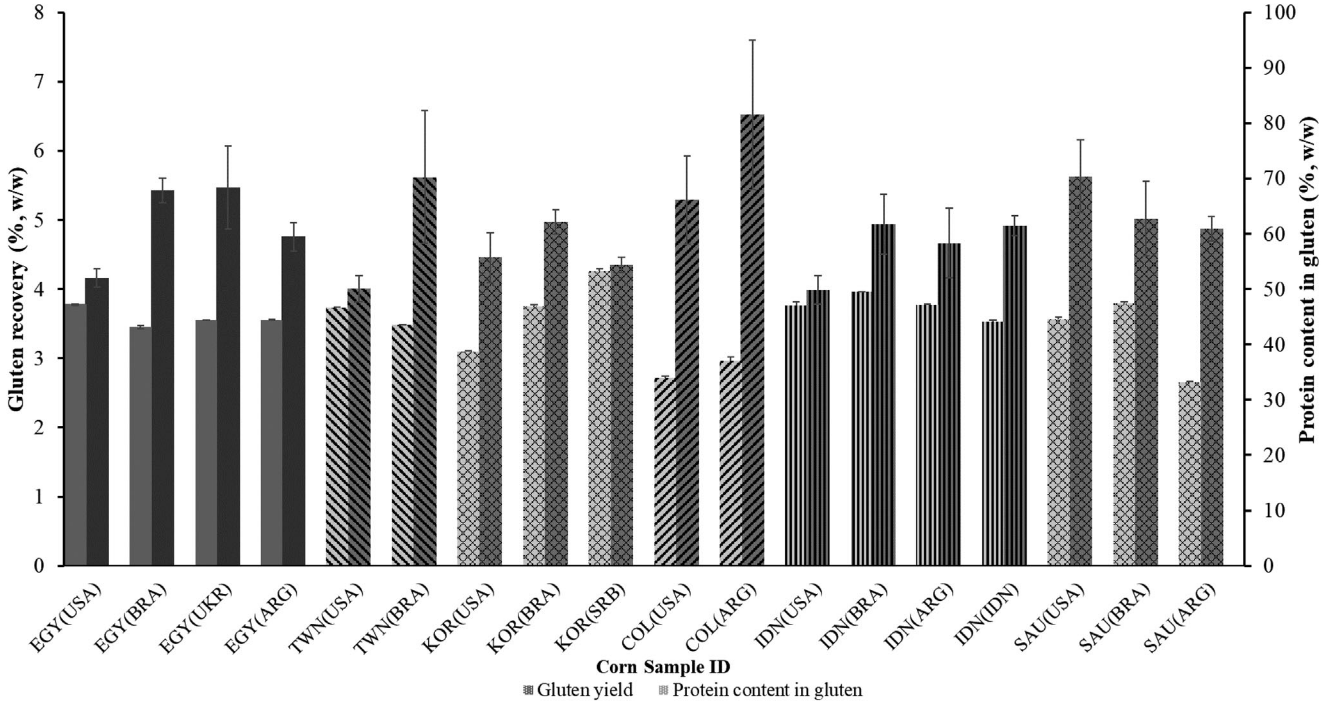

Figure 4. Wet mill gluten recovery and protein content comparison. Corn sample IDs represent the corn exported from the United States of America (USA), Brazil (BRA), Ukraine (UKR), Argentina (ARG), Serbia (SRB) to the countries of export Egypt (EGY), Taiwan (TWN), South Korea (KOR), Colombia (COL), Indonesia (IDN), and Saudi Arabia (SAU).

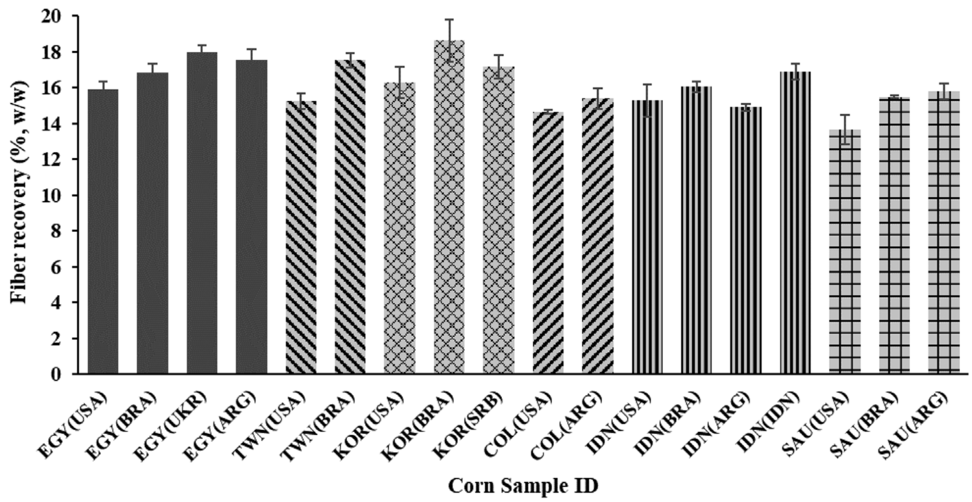

Figure 5. Wet mill fiber recovery comparison. Corn sample IDs represent the corn exported from the United States of America (USA), Brazil (BRA), Ukraine (UKR), Argentina (ARG), Serbia (SRB) to the countries of export Egypt (EGY), Taiwan (TWN), South Korea (KOR), Colombia (COL), Indonesia (IDN), and Saudi Arabia (SAU).

hard endosperm corn as floury starch is easier to recover in the wet milling process. Regardless of the limitations in the form of undesirable physical nature of the soft endosperm corn which results in higher breakage during transport, higher extractable starch is obtained from soft endosperm corn in wet milling process. An 8.13–13 million USD per year enhancement in revenue will be achieved when the soft endosperm US corn will be utilized in an efficient wet milling process over a plant using hard endosperm corn from other international origins.

4. Experimental Section

Corn Procurement: Corn samples grown in different geographical locations (countries) viz. USA, Brazil, Ukraine, Argentina, Serbia, and Indonesia, were acquired from arrival port terminals in Egypt, Taiwan, South Korea, Colombia, Indonesia, and Saudi Arabia. Throughout this study the corn sample IDs had been designated as the three letter of country for the collection location followed by three letters of another country in parenthesis which referred to origination location, e.g., EGY (USA), EGY (BRA), EGY (UKR), and EGY (ARG) represent that the corn samples were

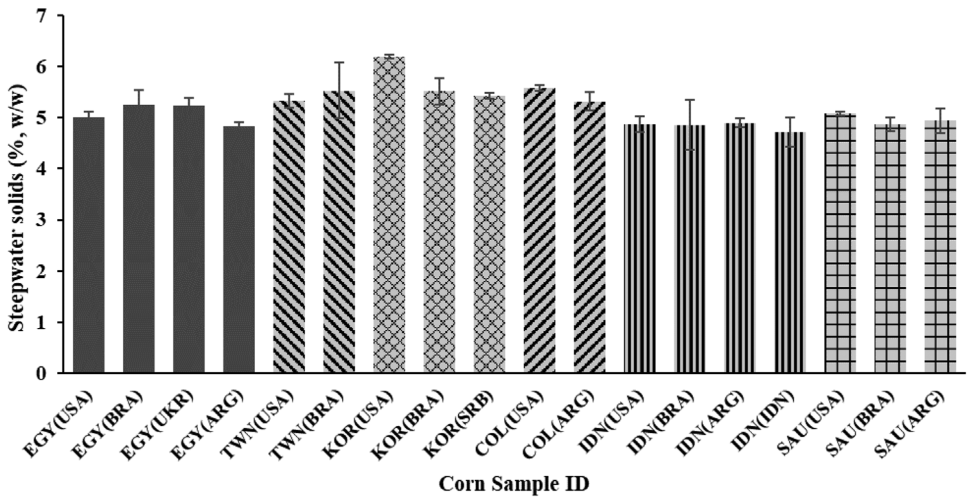

Figure 6. Wet mill steep water solids recovery comparison. Corn sample IDs represent the corn exported from the United States of America (USA), Brazil (BRA), Ukraine (UKR), Argentina (ARG), Serbia (SRB) to the countries of export Egypt (EGY), Taiwan (TWN), South Korea (KOR), Colombia (COL), Indonesia (IDN), and Saudi Arabia (SAU).

imported from the United States of America (USA), Brazil (BRA), Ukraine (UKR), and Argentina (ARG), respectively to the country of export Egypt (EGY). Similar sample IDs viz. TWN (USA), TWN (BRA), KOR (USA), KOR (BRA), KOR (SRB) where SRB denotes Serbia, COL (USA), COL (ARG), IDN (USA), IDN (BRA), IDN (ARG), IDN (IDN), SAU (USA), SAU (BRA), SAU (ARG) were designated for the corn procured from Taiwan (TWN), South Korea (KOR), Colombia (COL), Indonesia (IDN), and Saudi Arabia (SAU).

Three trucks per shipment vessel (single ship) arriving at the starch plant destination were sampled and then mixed in a 5-gallon plastic bucket for each sample. The mixed samples were air shipped to the University of Illinois, under APHIS (Animal and Plant Health Inspection Service, USDA) permit, in double-sealed plastic bags. All the corn samples were from crops grown in the year 2020. Samples were sieved through a 12/64 in. (4.8 mm) round hole sieve to remove and quantified broken corn and foreign material (BCFM). The kernels which passed through the sieve were stored in plastic bags at 4 °C until further processing.

Analytical Methods: Along with the chemical composition of commodity corn samples, the physical properties (floatation index/endosperm hardness, BCFM, test weight) were also determined. A Boerner divider was used to get exact representative samples of all the commodity corn being studied. A Boerner divider was a gravity-operated dividing apparatus, and it separated the samples into two smaller equal portions. The sample was fed from the hopper at the top and released by opening the valve at the bottom of the hopper. On opening the valve, the sample flowed downward and was evenly dispersed over a cone with evenly spaced separations. The chemical composition and BCFM of the corn samples were determined in a commercial analytical laboratory (Illinois Crop Improvement Association, Champaign, IL, USA). The chemical composition of all the samples was determined by near-infrared (NIR) transmittance (Foss GrainSpec, Foss Food Technology) by following a method reported earlier,[29] and BCFM was determined using USDA's Grain Inspection, Packers, and Stockyards Administration (GIPSA) method.[30] The procedure for determining BCFM involved two steps, machine cleaning (Carter Dockage Tester) and handpicking. Briefly, the air control in Carter Dockage Tester was set to 1 and the feed control to 10. The top sieve carriage contained the US No. 3 sieve, and there was no sieve in the middle and bottom sieve carriages. After starting the Carter Dockage Tester, about 1000 g sample was poured into feed hopper. For foreign material (all matter other than corn including sweet corn, blue corn, and popcorn) was removed from the mechanically cleaned portion and the mechanically separated and handpicked BCFM were combined later. The coefficient of variance (COV) for corn compositional analysis was below 0.93% and for BCFM was below 10% for the analytical laboratory. The kernel density of all the corn samples was measured by the floaters test to determine grain hardness, briefly, the three sets of 100-intact corn kernels were selected and 100 kernels were added to a 500 mL sodium nitrate solution (specific gravity 1.275 g cm^{-3}) and were agitated every 30 s for 5 min.[31] GIPSA test weight method was followed to determine test weights of the samples.[30] The method involved filling a pre-weighed empty test weight kettle with the corn kernels using a test weight per bushel apparatus which had a hopper with a valve at the bottom. The sample was poured in the hopper with the valve closed, the hopper was centered over the kettle and kettle was filled by opening the hopper valve quickly. Once hopper was empty, the hopper was moved all the way to the left before proceeding avoiding the jarring of the apparatus. The kettle was stroked by holding a standard stroker in both hands with the flat sides in a vertical position. The grain in the kettle was leveled by making three full-length, zigzag motions with the stroker. The kettle filled with the kernels was weighed and the gram weight was converted to the pounds per bushel (lb bu^{-1}) following the standard conversion tables suggested by USDA-GIPSA.[31] The moisture content of the corn samples was determined by drying them in hot air oven at 105 °C for 72 h (AACCI Approved method 44-15.02).[32] For wet milling experiments, all solid loadings mentioned included the moisture content as analyzed.

Wet Milling: Different fractions of the corn kernels viz. starch, protein, germ, fiber, and soluble content in all the samples were determined by following the Laboratory-scale 100 g wet milling procedure developed by Eckhoff et al.[16] with minor modifications to meet the requirements and for improved process efficiency. All the wet mill fraction yields were reported as a percentage of fraction (dry basis) of the total corn (dry basis). Moisture content of the fractions was determined using a two-stage convection oven method (AACCI Approved method 44-18).[32] All the experiments were performed in triplicate.

Laboratory-scale 100-g wet milling procedure involved the steeping of corn followed by repeated grinding, sieving, and starch separation steps. For steeping, the kernels were soaked in acidified water and sulfur dioxide under controlled temperature conditions. A coarse grinding of the steeped corn separated the germ from the kernel, and a sieving was performed to separate the coarse fiber and germ followed by the washing off starch and gluten with water. A second grinding and sieving was performed at this stage using a finer sieve to separate the fine fiber from the components, and starch and gluten were again washed off. Eventually, starch was separated from the gluten protein via a tabling step based on a density difference in the components. Different fractions (aqueous streams and solid residues) obtained in the wet-milling steps were stored for further analysis.

Data Analysis: The yields of the fractions obtained after wet milling were determined after two-stage drying, and the mass balance was calculated as the total of these yields compared to total initial sample used for wet milling. Percentage fraction yields were determined. The laboratory wet milling experiments and all analytical procedures were done in triplicates. Fraction yields and physical properties of the corn samples were compared using an analysis of variance (ANOVA) to determine differences in means. All statistical analyses were performed with the significance set to a *p*-value of 5% ($p < 0.05$) by using RStudio (2022.02.2 Build 485, RStudio PBC, Boston, MA, USA).

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Conflict of Interest

The authors declare no conflict of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Keywords

corn millability, soft endosperm corn, starch yield, wet milling

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