Physicochemical Investigation into Major League Baseballs in the Era of Unprecedented Rise in Home Runs

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Supporting Information

ABSTRACT: A major attraction of baseball is the home run. Throughout baseball’s history, some seasonal increases in home run numbers have been tied to external influences, such as lowering the pitching mound or a change in the ball manufacturer. In Major League Baseball, a recent surge in home runs has led to speculation about the baseball being “juiced” or altered in a way to make it fly farther. To support multiple academic and journalistic studies, which have attempted to find evidence of the changes in the flight of the baseball, a systematic chemical analysis has been reported on the multicomponent baseballs. Thus, we undertook a study where we analyzed the core of the baseball using various chemical and physical techniques. Studies using computed tomography scans revealed that there is a drastic 56.7% difference in the density of the core of the baseballs used during the 2014 and pre-All-Star Game 2015 versus 2017 season in the Major League. Increased material porosity was observed using electron microscopy. Thermogravimetric and elemental analyses of the pill material showed a 7% difference in the ratio of organic to inorganic material and almost a 10% decrease in silicon, respectively. Overall, the data indicates a difference in the core of the baseballs between the two time periods, leaving the contribution of these measured differences in the explosion of home runs open to interpretation.

INTRODUCTION

It is called “America’s pastime,” but baseball has a reach that spans the entire globe. It is a multibillion-dollar industry, where scores on the field or the number of home runs hit often drive the revenue and entertainment value.1,2 For this reason, in different professional leagues, changes are made from time to time to manipulate offensive production, specifically home runs. After the 1968 season, for example, Major League Baseball (MLB) lowered the pitching mound and openly acknowledged their intent to improve the offense. The 1969 MLB season saw the number of home runs per game increased by 31.1%, and the change was generally lauded.3 In a more questionable move from 2011, officials from Japan’s Nippon Professional Baseball (NPB) league secretly asked the baseball manufacturer Mizuno to tamper with the ball, also in an effort to improve offensive production. Home runs soared by 47%, but both the players and the public were confused as to why.

When the conspiracy was eventually revealed, the NPB commissioner resigned after being pressured to step down.4 Other times, the players have changed not the game parameters. During what’s been called the MLB’s “P.E.D. Era,” the illicit use of performance-enhancing drugs (PED) or steroids became prevalent for professional baseball players. Although MLB had banned steroids in 1991 and the choice to use PED was ultimately the individual’s, the goal was nonetheless, to increase performance which in turn could lead to increasing home run production and scoring. It was successful between 1996 and 2003, multiple individuals and team home run records were broken. This era came to a close in 2007, when more than 80 former and current professional baseball players were named in The Mitchell Report, an

Received: February 12, 2019
Accepted: August 13, 2019
Published: November 21, 2019

DOI: 10.1021/acsomega.9b00405
ACS Omega 2019, 4, 20109–20117

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investigation led by former United States Senator George Mitchell that examined the use of steroids in professional baseball.5

These examples highlight instances when increased offensive production can be linked to a specific change to the game, such as a difference to the ball, mound, or player physiology. This is why a recent surge in MLB home run production has generated some suspicion. Unlike previous offensive explosions, there is seemingly no change to the game that can explain this phenomenon. Home run numbers began to rise after the 2015 MLB All-Star Game, a time when teams typically replenish their baseball supply and has continued through the 2019 season. In 2019, the MLB is on pace to yet again break the record for home runs in a season, which was last done in 2017, when there were almost 50% more home runs per game in the MLB than during the 2014 season. Asked in 2017 by C&EN, “If the ball is the same as it was before, why are players hitting noticeably more home runs these days,” Alan Nathan, an academic expert on the physics of baseball, stated “I would say that’s still a mystery.”6

Although the Physics of the baseball and the biomechanics of the players have been studied reasonably well, the chemistry of the baseballs is a rather unknown entity. To investigate the differences in chemical compositions between the years 2014/pre-ASG 2015 and 2017, our data shows that there is a noticeable change in the physicochemical properties of the baseballs between the years 2014/pre-ASG (pre-2015 ASG) and the 2017 season (post-2015 ASG). Game-used baseballs have a short lifespan accordingly to the MLB. The average baseball is in the use for a duration of 6 pitches. All experiments were done with at least 3 different baseballs from each group.

**Baseballs.** Two sets of certified game-used baseballs were used for the studies, which were from before the 2015 ASG (pre-2015 ASG) and the 2017 season (post-2015 ASG). Game-used baseballs have a short lifespan accordingly to the MLB. The average baseball is in the use for a duration of 6 pitches. All experiments were done with at least 3 different baseballs from each group.

**CT Scans.** The game-used baseballs were scanned utilizing a 320 detector row Toshiba Aquilion One scanner (Canon Medical Systems, CA). The baseballs were placed on the scanner gantry, with two different scans performed. On the first scan, single-game-used baseballs from 2014/pre-ASG 2015 to 2017 were placed next to each other. On the second scan, four-game-used baseballs from 2014/pre-ASG 2015 and four-game-used baseballs from 2017 were placed next to each other. Measurement of the density of the internal components of the baseballs was performed by evaluating the Hounsfield units. These measurements were conducted on the Synapse Picture Archive and Communication System (PACS) (Fujifilm Medical Systems, Japan). Regions of interest were placed on the different layers of the baseball components, with particular interest on the Hounsfield units in the different layers of the baseball pill. A visual “heat map” of the 2014/pre-ASG 2015 and 2017 baseballs, based on the internal radiodensity as measured by Hounsfield units, was created by processing the CT data on Synapse 3D (Fujifilm Medical Systems, Stamford, CT).

**SEM Microscopy.** The rubber from the outermost pill layer (pink layer) was sliced into small parts, and then the samples were loaded on the conductive carbon adhesive tabs for scanning electron microscopy (SEM) imaging (Electron Microscopy Sciences, PA). The SEM measurements were conducted on a Hitachi S-2600N microscope of various regions of each sample, where the figures display the average of those measurements.

Figure 1. Among all of the US professional baseball leagues, only in MLB did the seasonal league home records exceed yearly average. MLB home runs exceeded yearly averages since the 2016 season. Annual home run records were collected for professional baseball leagues (top left) MLB (top right) and Minor League Divisions from 1994 to 2019. The PED era is referenced from 1994 to 2003 where PED testing started in 2003. The 2019 AAA season was circled in green to indicate the initial use of the MLB baseball compared to the minor league baseball that has been used the 25 seasons before where a 52% increase in home runs has occurred. (Bottom) A tabulated version of A and B showing the 20 year average; post-PED era average (2004−2015); the 2016−2019 seasons home run per game totals.
Professional baseball in the United States has a number of professional development leagues that serve as a farm system for MLB. The company Rawlings produces all of the baseballs that are used in the Major and Minor League systems, but the Major League uses balls entirely from the manufacturing unit in Costa Rica, whereas the Minors use balls produced in China.\(^7\) When the year-to-year averages across the different leagues are examined, it became rather clear that the unusual surge in HRs was observed only in the MLB may be linked to the baseballs. Extrapolating HR per game across the last 26 years in the Minors, as in Figure 1 with the Majors, we see similar trends up to 2014, but clearly, the recent surge in HRs exceeding historical records was not observed in the analysis (except in 2019 for the AAA). All Minor league divisions registered peaks of HR per game during the PED era and regressions from 2004 to 2015 (specifically a 3% reduction in AAA and AA, which was identical to the MLB) following the trend in MLB, highlighting the consistency between the four professional leagues. All three minor league divisions also showed an upward trend of HRs in recent years, but the HR/game ratios were all equal or less than the 20 year average and similar to the 2004–2015 average, as shown in Figure 1 (bottom). Interestingly, as of the 2019 season, the AAA Minor League started using the MLB-issued baseball. As of May 16th of 2019, AAA players were hitting 1.34 HR/Game, which was a 52% increase from the previous year. This stark difference with the addition of the MLB baseball and the lack of difference in similar HRs trends in the other minor league systems only further emphasized the tremendous increase in HRs observed in the MLB and indicated the first possible sign correlating this occurrence to the baseballs. Other statistical factors were assessed to ensure that the increase in HRs was not the product of a gameplay factor. Figure S1 plots the average hits per game in the MLB across the same time span, showing that the last 8 years have seen a 5–7% decrease in hits per game compared to the 18 years. This is also consistent with an increase in strikeout rates, which indicate that pitching improved as time went on, possibly making hitting HRs more difficult (Figure S2). When hits per HR was normalized, the same trend was observed in Figure 1, indicating an enormous increase in the frequency of HRs (Figure S3). The number of at-bats (or offensive attempts of a baseball player) per HR was also assessed to account for a small season to season deviations of at-bats due to extra-inning games or an increase in hits. The same trend existed in at-bats per HR as with the frequency of overall HR. The number of HRs hit increased in frequency, from on average every 37.5 at-bats to below every 30 at-bats starting in 2017 (Figure S4).

One of the most common explanations used for the increase in HRs is a difference in the approach of batters attributed to analytics deprioritizing strikeouts. Hitters are thought to be

**RESULTS**

Beginning in 2015, Major League Baseball has Witnessed More Home Run than Ever Before. The analysis of year-to-year home run (HR) ratios was first compiled to understand how the current trend compares within the last 26 years (Figure 1, left panel). Season statistics were obtained from baseball-reference.com, mlb.com, and foxsports.com. To account for the differences in gameplay over the years, HR per game was calculated since the beginning of the PED era (1994–2004) to 2019. The 2015 season registered a noticeable trend that started in the MLB when HRs began increasing dramatically and continued through the 2019 season. This is contradictory to the regression observed starting from the 2004 season and ending in 2014, when 2014 registered a 26 year minimum. What makes this trend more interesting is that the 2016 season was just shy of breaking the all-time major league record for cumulative single-season HRs, whereas in 2017, the reigning league HR record, achieved in 2000, was surpassed by 9%. This is a stark difference compared to the aforementioned 26 year minimum observed just a few years back in 2014, resulting in overall a whopping 46.5% difference in the number of HRs hit in the short time frame of the 2014 and 2017 seasons.

Professional baseball in the United States has a number of professional development leagues that serve as a farm system for MLB. The company Rawlings produces all of the baseballs that are used in the Major and Minor League systems, but the Major League uses balls entirely from the manufacturing unit in Costa Rica, whereas the Minors use balls produced in China.\(^7\) When the year-to-year averages across the different leagues are examined, it became rather clear that the unusual surge in HRs was observed only in the MLB may be linked to the baseballs. Extrapolating HR per game across the last 26 years in the Minors, as in Figure 1 with the Majors, we see similar trends up to 2014, but clearly, the recent surge in HRs exceeding historical records was not observed in the analysis (except in 2019 for the AAA). All Minor league divisions registered peaks of HR per game during the PED era and regressions from 2004 to 2015 (specifically a 3% reduction in AAA and AA, which was identical to the MLB) following the trend in MLB, highlighting the consistency between the four professional leagues. All three minor league divisions also showed an upward trend of HRs in recent years, but the HR/game ratios were all equal or less than the 20 year average and similar to the 2004–2015 average, as shown in Figure 1 (bottom). Interestingly, as of the 2019 season, the AAA Minor League started using the MLB-issued baseball. As of May 16th of 2019, AAA players were hitting 1.34 HR/Game, which was a 52% increase from the previous year. This stark difference with the addition of the MLB baseball and the lack of difference in similar HRs trends in the other minor league systems only further emphasized the tremendous increase in HRs observed in the MLB and indicated the first possible sign correlating this occurrence to the baseballs. Other statistical factors were assessed to ensure that the increase in HRs was not the product of a gameplay factor. Figure S1 plots the average hits per game in the MLB across the same time span, showing that the last 8 years have seen a 5–7% decrease in hits per game compared to the 18 years. This is also consistent with an increase in strikeout rates, which indicate that pitching improved as time went on, possibly making hitting HRs more difficult (Figure S2). When hits per HR was normalized, the same trend was observed in Figure 1, indicating an enormous increase in the frequency of HRs (Figure S3). The number of at-bats (or offensive attempts of a baseball player) per HR was also assessed to account for a small season to season deviations of at-bats due to extra-inning games or an increase in hits. The same trend existed in at-bats per HR as with the frequency of overall HR. The number of HRs hit increased in frequency, from on average every 37.5 at-bats to below every 30 at-bats starting in 2017 (Figure S4).

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![Image](https://example.com/image.png)

**Figure 2.** Despite fewer fly balls hit more home runs were being scored during the last 26 years. (Left) Year-to-year ratios of home runs to fly balls were plotted from 1994 to 2019. (Right) MLB batters groundball (GB) to fly ball (FB) ratio from 2002 to 2019 are plotted. The 18 year average ratio is 1.24 GB/FB (GB and FB stats acquired by FanGraphs, which started recording team GB and FB stats in 2002).
intentionally trying to lift or raise the trajectory of the baseball more and hit more fly balls, in turn, resulting in more HRs. To investigate this theory, the relative ratio of HR per fly ball hit was again plotted over the last 26 years (Figure 2, left). From 1994 to 2014, the HR to fly ball ratio almost remained the same with a slight increase during the PED era, as would be expected. But contradictory to the 0.106 average ratio, during the 2017–2019 seasons, there were 47, 68, and 93% increase in the chance of a fly ball to be hit as a HR compared to the 20 years prior to the 2014 season. This is noteworthy as the variation between the highest and lowest statistical points was only 9% compared to the average from 1994 to 2014.

The numbers reported here as well as reported by other baseball analysis writers show a drastic change in global MLB HR production that was sparked almost immediately in 2015. Interestingly, the recent 50% increase in AAA HR with the

Figure 3. CT scans show a change in the radiodensity of the inner pill of the baseball. MLB baseballs from 2014/pre-ASG 2015 (left) and 2017 (right) were observed for changes in radiodensity using CT, as measured using Hounsfield Units. (A) Heat map representing the difference in HU and (B) CT scan of baseballs from 2014/pre-ASG 2015 (left) and the 2017 season (right). This experimentation allowed for each component of the baseball to be visualized, allowing us to determine which portion of the materials displayed any variation from 2014/pre-ASG 2015 to 2017. The inner pill, made of 3 components (pink rubber outer layer, black rubber inner layer, and a cork center) saw a 56.7% decrease in radiodensity between the two baseballs. (C) Compiled Hounsfield Units observed from CT scans of various game-used baseballs from the 2014/pre-ASG 2015 and 2017 season. Statistical significance of the outermost layer of the pill is \( P < 0.001 \).
addition of the MLB baseball only strengthen the argument that the baseball can be the catalyst of these unprecedented HR numbers. But it should also be noted that the average pitch velocity has increased almost 4 MPH since the early 1990s and over 1 MPH in the last 6 years.8 Pitchers are also exceeding 95 MPH roughly 22% of the time, which represents more than 50% increase since 2008.8 Along with the already mentioned strikeout rates steadily increasing, these are reasons why it is thought that pitcher performance is driving causation in increase of HRs as well. This is shown in Figure 2 (right panel) where the ratio of groundballs to fly balls has dropped from 1.32 to 1.2 from 2014 to 2019 as players have had tendencies to lift the ball more. This similar trend was seen at the end of the PED era as well where players hit at 18 year minimum of 1.14 groundball to fly ball ratio in 2007. The ability to hit a HR is thought to be a better gameplay strategy by some analysts in terms of scoring runs than getting multiple hits in a row based on the improved performance of the average pitcher. This all speaks to the complexity of the dynamics on what goes behind hitting a HR and the reasons why there is such a drastic change in HR scored, but it still does not explain the suddenness of the change.

**CT Scans of Baseballs Showed Differences in Density between the Pills.** Although the physics of the baseball has been studied in some detail, to our knowledge there are no published peer-reviewed data available on the systematic analysis of the chemical composition and the characteristics of the internal components of a baseball. To assess the density of the baseballs from the two different time periods, CT scans were performed without needing to break or open the balls. The measurements were obtained using Hounsfield units (HU). By definition, the HU scale is effectively a measure of the linear attenuation coefficient of X-rays passing through an object, which has been converted to a scale at which the measured radiodensity of distilled water at standard temperature and pressure is defined to be zero HU. The HU of air is measured to be ~1000. For example, human lipomatous (fatty) tissue measures approximately ~120 to ~90 HU, as it is less dense than water and would, therefore, float on water. Denser materials such as metal, stone, and glass measure much higher (from 500 to 20 000 HU) depending on the composition and atomic number of their internal contents. The radiodensity of the different components of the inner pill of the baseball clearly differs when comparing the two time periods. Furthermore, the measured HU also demonstrate a significant difference (Figures 3 and S5–S7). Specifically, the outermost layer of the inner pill of baseballs from before the 2015 All-Star game was 56.7% denser on average. Other parts of the pill did not seem to be affected as the cork interior and inner rubber layer had relatively the same densities in baseballs before the 2015 All-Star game and in 2017.

**Chemical Analysis Shows Differences in Material Composition.** The CT scans established a narrower target for the potential area that showed a distinct difference between the new and the old baseballs. As mentioned earlier, the inner pill of a baseball is made up of three components, an outer pink rubber layer, a middle black rubber layer, and an inner cork (gray). For chemical experimentation, portions were taken from the specific layer to assess potential differences from baseballs used in 2014/pre-ASG 2015 and 2017. (B) The pills of new baseballs weigh 0.5 g less on average than older pills. The pill of baseballs from 2014/pre-ASG 2015 and 2017 was weighed and averaged were calculated. Baseballs from 2017 were observed to weigh approximately 0.5 g less. Three pill samples from each 2014/pre-ASG 2015 and 2017 game-used baseballs were assessed.

![Figure 4.](image)

Figure 4. Inner pill of the baseballs displays physical differences. (A) Deconstructed pill showing the inside of the pill of a major league baseball. The pill of baseball from 2014/pre-ASG 2015 and 2017. The pill is made of 3 components, an outer pink rubber layer, a middle black rubber layer, and an inner cork (gray). For chemical experimentation, portions were taken from the specific layer to assess potential differences from baseballs used in 2014/pre-ASG 2015 and 2017. (B) The pills of new baseballs weigh 0.5 g less on average than older pills. The pill of baseballs from 2014/pre-ASG 2015 and 2017 was weighed and averaged were calculated. Baseballs from 2017 were observed to weigh approximately 0.5 g less. Three pill samples from each 2014/pre-ASG 2015 and 2017 game-used baseballs were assessed.

Insignificant and within the acceptable range of the baseball weight (5.00–5.25 ounces according to rule 3.01 of 2017 Official Baseball Rules).9 But in the context of the pills, the weight is significantly different and provided further evidence that the pill between the years had changed.

Since the CT scans demonstrated that only the outer pink layer was significantly different, the material from the layer was examined using various experiments to determine potentially what chemical changes could have occurred. It should be noted that there is an observable difference in the color of the balls. All of the new baseballs contained a lighter shade of pink. Apart from concluding a difference based on color, thermal gravimetric analysis (TGA) was performed to investigate if the chemical composition of the balls changed, particularly the amount of the inorganic material used. Across a temperature range of 25–800 °C, five distinct regions were examined for material changes based on differences in the mass percentage of loss of the material versus starting material (Figure 5A,B). Most notably, there was a 7% difference in the mass left over after the high-temperature gradient, accounting for a difference
may result from different amounts of intermolecular interactions that the varying material compositions could possess.

To learn more details about potential differences in the chemical composition of the baseballs, infrared spectrometry (IR) was used to determine if the chemical functionalities are different within the pink rubber layer. We reasoned that chemical shifts based on the functional group difference within IR could potentially detect composition difference of the type of the polymer material used. Figure S12 shows only slight increases in intensity at peaks of 700, 1540, and 1570 nm in the new ball compared to that of the old baseballs. The rubber pills were later dissolved in various solvents with different chemical properties in an effort to obtain a better understanding of the potential changes in the material. The IRs of the pills soaked in chloroform showed the same difference observed earlier with the additional absorbance at 1540 nm. The observed changes are only minor increases, which are thought to be concentration dependent, although may not be linear. The vast majority of the IR spectra across four different solvents and the raw material showed extremely similar results indicating that from the perspective of chemical functionalities, there is no significant difference between the old and new balls. Overall, this suggests that the nature of the material used in the outer layer of the rubber is the same and that no new material was added to the rubber between the old and new baseballs.

As mentioned earlier, the CT scans signified a 56.7% difference in radiodensity between the outer pink layer in the new and old baseballs. Changes in these densities could be explained by the porosity of the material. The mass decrease seen in Figure 4B could be a result of increased pore formation and, therefore, less mass in a constant volume from pills of different years. Scanning electron microscope (SEM) images of the new and old balls were obtained and they showed that the new balls had more pores in the material compared to the old (Figure 6). The pores were visually larger, and these images were indicative of the entire body of the material. SEM-coupled energy-dispersive X-ray spectroscopy (EDS—SEM) of multiple regions of old and new balls displayed that identity and number of elements were unchanged. SEM-coupled X-ray

Figure 6. Material of new baseballs (2017) was displayed to be more porous. (A) SEM was used to view the pink rubber layer of the new (2017) and old baseballs (2014/pre-ASG 2015). Larger pores at a higher number were observed across the entirety of the material of the new baseballs. The increased porosity of the new baseballs specifically correlates with the CT findings that demonstrate a 56.7% higher density in the core of the 2014/pre-ASG 2015 baseballs compared to the 2017 baseballs.
diffraction elemental mapping (EDS–SEM) of multiple regions of old and new balls displayed that identity and number of elements were unchanged. However, the amount of certain elements changed significantly (Figure 7). Particularly, the largest change was observed in relative Si percentage, which decreased by 10%. This further explains that the reduction of the inorganic material confirmed in the early TGA experiments as Si is observed to be the dominant inorganic species within the pink rubber. Sulfur within the pink layer of the new baseballs exhibited a 2% decrease. Carbon composition was experimentally determined to increase 5% in the new baseballs through elemental decomposition analysis. This change can be further explained by the increase in the polymer content seen in Figure 5B. The polymer within the shell was thought to be the dominant supplier of carbon. Together, the elemental analysis further concluded that less inorganic material and more polymer is present within the pink pill of the new baseballs.

**DISCUSSION**

In recent years, the home run rates in MLB have increased at a staggering rate, prompting the entirety of the baseball world (from fan to player) to look for plausible reasons behind it. The most common explanations have consisted of changes in philosophy (specifically more fly balls), improved technologies that result in improved training, and a changed baseball. Increasing HR/Flyball rates and the sudden 5 year surge in HRs are thought to have rendered the first two options unlikely or secondary factors, as they would have resulted in a constant, subtle increase year to year. This recent dramatic difference is similar to what was observed during the PED era when an external factor improved player performance. CT scans looked into each component of the baseballs, initially confirming a change of radiodensity of the inner, central pill (specifically the outermost layer) of the baseballs from 2014/ pre-ASG 2015 to 2017. The chemical analysis further resolved the outermost pink layer, defining significant differences in porosity, weight, and relative Si and polymer contents, marking an alteration in the sampled balls.

The work performed here does not directly compare the chemical composition to the dynamics of the baseball’s flight and collision dynamics; however, a number of reports have examined how these new baseballs in theory and practice have shown significant performance alterations. Physics of the ball—bat collision is highly variable, as countless factors can manipulate ball flight. One such possible change could occur based on the change in the density, which has shown to result directly in a significant decrease in the mass of the pill. This 0.5 g difference has mirrored a similar decrease in the overall weight of the baseballs, but this change is within the error of measurement deemed acceptable by the MLB. One thought is that the subtle difference in ball weight could change the ball exit speed off the bat. Ball exit speed ratio (BESR) is used to observe the speed at which the ball will be hit. As the mass decreases, BESR increases. If consistent, even a 0.5 g change can increase the exit ball velocity off the bat, but it is unknown if this weight difference would be enough solely to make a large change in the flight distance. But as average pitch speed has also increased in recent years, the two can complement each other for improved bat exit speed velocities. Also, it should be noted that although a less massive ball will come off the bat at a higher speed, it will be affected more by the air resistance. The coefficient of restitution (COR) or bounciness is another characteristic of the baseball that could have been changed. An article by The Ringer in 2017 explained that newer baseballs, from 2016 to 2017, had a “noticeably

Figure 7. Elemental composition changes dramatically between the new and old baseballs. (A) Silicon composition decreased 8% in new baseballs. EDS–SEM was used to observe the elemental composition. Multiple positions ($n = 3$) within the material of old and new baseballs were subjected to the EDS and those numbers were averaged to gain the composition for a single baseball. Multiple baseballs ($n = 3$) were used to get an average comparison among new and old baseballs. (B) Sulfur composition decreased 2 fold in new baseballs. EDS–SEM was used to observe the elemental composition. Multiple positions ($n = 3$) within the material of old and new baseballs were subjected to the EDS and those numbers were average to gain the composition for a single baseball. Multiple baseballs ($n = 3$) were used to get an average comparison among new and old baseballs. (C) Carbon composition increased 5% in new baseballs. Elemental decomposition analysis was used to quantify the carbon composition within the new and old baseballs. Multiple baseballs ($n = 3$) were used to get an average comparison among new and old baseballs. The increased carbon could be an indication of increased polymer content.
higher” COR than baseballs from 2014.14 Further investigation could be done to establish if there is a possible connection between a more porous pill and baseball COR. Finally, an investigative piece by Fivethirtyeight.com reported that baseballs have become less air resistant as well. Also, Nathan et al. in 2017 investigated how the baseball carried at Tropicana Field, an enclosed complex where the atmospheric effects can be assumed to remain constant.15 The results concluded that an aerodynamic change in the baseball could account for the significant difference in HR pre and post the 2015 all-star game (comparing the 2015 and 2016 seasons). However, this aerodynamic effect could not be attributed to the constant increase seen in 2017. Other factors can be plausible for the difference in HRs, in which the MLB has already looked into. Nathan et al. highlighted a humidor effect where the flight of the baseball is consistently altered by the environment in which the balls are stored in, specifically the humidity.16 Reducing moisture from the baseball can increase the COR of the baseball and, therefore, increase home run potential of the baseball. This has been a stated problem with ballparks located in such dry, lower humidity climates like Arizona and Denver. The MLB commissioner has called for the standardization of ball storage across the MLB for this reason and mandated that ballparks create controlled rooms in 2018.

In the Spring of 2018, a committee of scientists was formed in an effort to better understand the causation behind increasing HR rates in reference to the baseball. Their findings within the “Report of the Committee Studying Home Run Rates in Major League Baseball” concluded that baseballs manufactured in recent years (2016 and 2017) have a reduced drag compared to baseball manufactured from earlier years (2012–2015), whereas other factors such as possible material changes, COR, seam height, and launch angles did not make a significant difference.17 But the report did mention that Rawlings verified a difference in the manufacturing process of the pill where new molds were used starting in 2015 due to the older molds becoming worn out. This can very likely be the reasoning behind the differences in pill composition found within our study, which even highlights the improved reproducibility of the new molds as the variations found in the new pills were smaller compared to the older pills across all chemical tests done. The MLB report further stated that more tests are being performed but “does not rule out the possibility that manufacturing advances have contributed to the reduced drag by creating a more spherically symmetrical ball with a more properly centered pill (which would in theory lead to a lower drag)". This MLB report may not directly confirm the changes we found within the pill attributes toward increases in HR, but it does highlight the change in the manufacturing process of the pill that is thought to be an underlining reason for changes in drag and carry, and the manufacturing process created a different pill as seen by our chemical study.

CONCLUSIONS

Through this investigation, specific changes to game-used baseballs before and after the 2015 All-Star game were found. Initially, CT scans were able to observe each of the larger components of the baseballs to narrow down a reoccurring difference in density of the outermost layer of the baseballs’ core. This rubber component was then put through numerous chemical experiments demonstrating that the material’s inorganic/organic composition changed creating a more porous structure, but the specific components remained the same. As the compiled results demonstrated that an empirical change had occurred between the cohorts of baseballs from 2014/pre-ASG 2015 to 2017, the potential reason behind such change cannot be ascertained from our studies. But a 2018 report does conclude changes in the manufacturing process leading to a different pill during 2015, aligning with the data in this report. Potentially the chemical tests done can have a role in determining future indications of the ball performance going forward. Previous changes to a professional baseball, for a multitude of reasons, have resulted in a number of different performance outcomes, as previously stated.16 As thousands of baseballs are put into play every year, we believe that this study should be taken as a potential starting point for a larger study in an effort to understand these changes in the pill and the baseball as a whole, to create new targets, which can be tested to observe the ball performance.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acsomega.9b00405 §

S1, hits per game average in MLB; S2, strikeouts per game in MLB; S3, hits per home run in the MLB; S4, at-bats per home run in the MLB; S5, CT scans of MLB baseballs from 2017; S6, CT scans of MLB baseballs from 2014 to 2015; S7, raw images of CT of MLB game-used baseballs; S8, TGA of outer core of the MLB baseballs at 240 °C; S9, TGA of outer core of the MLB baseballs from 300 to 500 °C; S10, TGA of outer core of the MLB baseballs at 500 °C; S11, TGA of outer core of the MLB baseballs at 600 °C; S12, IR spectrometry of the outer core of MLB baseballs (PDF)

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Experiments were performed by N.B., L.Z., M.L., and J.A. Data analysis was performed by N.B., L.Z., M.L., D.H., J.A., and S.B. The manuscript was written by N.B., L.Z., M.L., J.Z., and S.B.

Notes

The authors declare no competing financial interest.

ACKNOWLEDGMENTS

This work is supported by Kent State University and University. We thank the Liquid Crystal Institute at Kent State University for helping with SEM experiments. We thank Dr. Mietek Jaroniec for the assistance with the thermogravimetric analysis. We thank Dr. Chris Blackwood and Anthony Minerovic for the help with carbon analysis of the baseballs. Tim Dix was instrumental in creating a research plan and developing the investigation into the potential material change into the MLB baseballs.

ACS Omega 2019, 4, 20109–20117

DOI: 10.1021/acsomega.9b00405
ACS Omega 2019, 4, 20109–20117
ABBREVIATIONS

CT, computed tomography; MLB, Major League Baseball; PED, performance-enhancing drugs; ASG, All-Star Game; SEM, scanning electron microscopy; PACS, Synapse Picture Archive and Communication System; EDS, energy-dispersive X-ray spectroscopy; TGA, thermogravimetric analysis; HR, home run; HU, hounsfield units; IR, infrared spectrometry; EDS−SEM, energy-dispersive X-ray spectroscopy; BESR, ball exit speed ratio; NCAA, National Collegiate Athletic Association; COR, coefficient of restitution

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