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Using Partial Budgeting Analyses to Analyze Profitability of Commercial Pumpkin Production, Standardize Bin Size Categories, and Understand Bin Sorting Accuracy

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Abstract. **Pumpkins (*Cucurbita* sp.) are currently sold in retail commercial bins categorized based on fruit size. There are no standards for these fruit sizes, thus creating discrepancies across the industry. Furthermore, there is not a published partial budget analysis for pumpkin fruit yield based on plant area. An observational study was conducted to quantify and standardize the fruit sizes of pumpkins packed into commercial bins. These proposed standardized fruit sizes were then correlated to the expected fruit size and quantity of different plant areas to estimate the total commercial bin yield. Additionally, a partial budget analysis was conducted to calculate the greatest profit per hectare with the varying plant areas. Pumpkins from bins labeled medium, large, extra-large, and jumbo were hand-measured to determine the diameter, length, and weight. Based on a discriminate analysis, 20% of pumpkins were incorrectly sorted based on current practices. The proposed standard fruit diameters for each bin size are as follows: medium, 23.5 to 26.8 cm; large, 26.9 to 29.9 cm; extra-large, 30.0 to 33.6 cm; and jumbo, 33.7 to 35.5 cm. The results of a partial budget analysis showed that the most profitable plant spacing area is 0.9 m^2 with a 1.5-m row width, which will earn $37,163/ha. Profit for pumpkin production is contingent on both fruit quantity and fruit size because these factors dictate the quantity and category of commercial bins. Growers should consider both metrics to optimize their operation.**

The US pumpkin (*Cucurbita* sp.) production has increased in the last 20 years, with total production increasing from 421.7 million kg in 2000 to 538.5 million kg in 2010 and, most recently, 848.4 million kg in 2021 (USDA ERS 2022) (converts from cwt to kg). Among the states surveyed by the US Department of Agriculture, including top producers Illinois, Indiana, California, Pennsylvania, and New York, the industry is valued at $233 million, with more than 281.7 km harvested in 2021 (USDA NASS 2022). The top uses for pumpkins in autumn include Halloween jack o' lanterns, agritourism activities, and seasonal food products (US Department of Agriculture, Economic Research Service 2015). These uses are increasing in popularity, thus causing a growth in demand, as seen from 2000 to 2014, with consumer usage increasing 17% per capita (USDA ERS 2015).

North Carolina has recently entered the top pumpkin-producing states, ranking sixth in 2019 (USDA NASS 2020). Most commercial growers in North Carolina harvest between 4046 and 20,234 m of pumpkins as a supplemental income to their large staple crops (North Carolina Department of Agriculture and Consumer Services 2023). Larger quantities of pumpkins are grown in the North Carolina western mountain region of the state, where the climate is cooler and the disease pressure is lower compared with the Piedmont and coastal regions in the east (Craddock 2022). In 2021, the state harvested 14,839 tons of pumpkins across 14.39 km of land. The state had an average price of $2.02/kg, with the total value of used production at $7.3 million (USDA NASS 2022).

Commercially shipped pumpkins are sold in standardized cardboard bulk bins. Pumpkins are sold by bin units rather than by individual fruit. These bins are either 60.96 or 91.44 cm in height and fit on a standard pallet that measures 99.06 cm by 109.22 cm (Aegerter et al. 2013). Carving pumpkins are sorted based on size and are packed into bins with comparably sized fruit. This usually happens during harvest, when pumpkins are sorted and packed in the field (Sexton G, personal communication). The bins are subjectively sorted and labeled according to fruit size into categories of medium, large, extra-large, or jumbo (USDA ERS 2022). Each fruit is marked with a sticker denoting its fruit size category. Bins are also labeled by the bin count, which is the projected number of pumpkins within a bin. Each bin count number is associated with a fruit size category. The bin size category with smaller fruit has a higher bin count, whereas a bin with larger fruit has lower bin counts. Bin counts are a projection rather than an actual count and can create discrepancies between the bin count label and the actual number of pumpkins within the bin. Cardboard bin heights, 60.96 or 91.44 cm, may vary based on preference and are not directly associated with a specific fruit size or bin count. Wholesale bin prices do not change based on fruit size or bin count (USDA ERS 2022). Growers can receive the same price for a 55-bin count of medium pumpkins and 20-bin count of jumbo pumpkins.

The US Department of Agriculture, Agricultural Marketing Services create voluntary grades and standards for horticultural crops. Grades and standards establish a method to define and measure the value of a crop to create a common language for buyers and sellers (Kader 2002; Spangler 1956). Grades define the quality metrics of a commodity, whereas standards define other parameters such as commodity uniformity and packing requirements (Spangler 1956). There are grades and standards for more than 80 horticultural crops (Kader 2002).

The US pumpkin industry does not have size standards, even though the fruit is sold primarily based on size. Other crops, such as watermelon (*Citrullus lanatus*), have specific size parameters and tolerances (US Department of Agriculture, Agricultural Marketing Services 2021). The last publication by the US Department of Agriculture regarding pumpkins was the *US Standard for Fall and Winter Type Squash and Pumpkin*, published in 1983, which lists two grades but no size standards (US Department of Agriculture, Agricultural Marketing Services 1983). Additionally, there are no industry resources that correlate the pumpkin bin category to the average fruit size for the North Carolina

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region (Sexton G, personal communication). Without regulation and guidance, fruit sizes can vary within the same labeled bin category depending on the region, farm, or employee who sorted and packed the bin. Furthermore, pumpkins have a large fruit size range, which introduces additional variations. For example, a seed company lists two cultivars, Magician and Howden Biggie, as producing big pumpkins. The maximum predicted fruit weight for 'Magician' is 16 lb, whereas that for 'Howden Biggie' is 22.67 kg (Harris Seeds, Rochester, NY, USA). This wide range of fruit sizes between cultivars is amplified when fruit are subjectively categorized and sold in bulk bins. Without standard sizes for pumpkins, there is no common language between buyers and sellers, creating a discrepancy in value.

The retail pumpkin season comprises September and October, with wholesale pumpkin bin prices increasing closer to Halloween, when the fruit is most demanded. During the 2021 season, the price for a bin of conventionally grown 'Howden' pumpkin started at $160 in early September and ended at $220 during the last 2 weeks of October, with the seasonal average being $190 across both bin heights (USDA ERS 2022). During the weeks leading up to Halloween, the advertised retail price of a 'Howden' pumpkin peaked during the second week of September at $5.82 per pumpkin (USDA ERS 2022). Carving pumpkin prices fluctuate based on location and date, whereas pie and specialty pumpkins prices remain constant throughout the fall season. The top-producing state Illinois grows food-processing pumpkins, which results in the lowest price at $3.53/cwt (USDA NASS 2022). In 2021, Washington had the highest price at $0.07/kg. Prices in North Carolina have increased during the last few years from $0.31 to $0.45 to $0.49/kg during the years 2019, 2020, and 2021 respectively (USDA NASS 2022).

Many studies have shown that decreasing the plant growing area decreases the fruit size. This was reported for both vine-type Howden and semi-bush-type Wizard cultivars, which decreased in fruit size as the plant area was reduced (Reiners and Riggs 1997). During another study, the fruit size decreased for vine-type 'Dickinson', but it did not decrease for bush-type 'Frosty' as plant spacing was decreased (El-Sayed et al. 2011). The conflicting results for 'Frosty' were attributed to the impact of genotype on growth habits of the vine-type and bush-type cultivars. The trend of decreasing fruit size can be seen with other cucurbits, such as watermelon, whereby decreasing in-row spacing decreased the fruit weight (Brinen et al. 1979; Sanders et al. 1999). These studies showed that plant spacing contributes to fruit size.

In addition to impacting the individual fruit size, plant spacing also impacts the overall yield (Weiner 1990). High-density spacing, which is equivalent to a smaller plant growing area, maximizes yields of vegetable crops (Maynard and Hochmuth 2007). The crop yield will increase with the increased plant density until the carrying capacity is met and a final constant yield is achieved (Weiner 1990). Several pumpkin studies have resulted in increased total fruit weight and fruit number per hectare when the plant growing areas for multiple pumpkin genotypes were decreased (El-Sayed et al. 2011; Reiners and Riggs 1999). This is seen with other crops; the total yield increased for squash and watermelon with the decreased plant growing area (Dweikat and Kostewicz 1989; NeSmith 1993).

Even though pumpkin studies have investigated the effect of plant spacing on fruit size and fruit yield, there are no resources that translate this yield into predicted commercial bins. Growers could accurately predict yield and prepare for harvest if they understood the expected bin category and quantity based on their management practices. Furthermore, growers can optimize production by leveraging plant spacing and bin size categories to find the highest yielding combination. This can be achieved by using a plant growing area that grows the most pumpkins per hectare at the correct fruit size that returns the highest number of bins. Creating a resource of bin production based on plant growing area would enable growers to make informed management decisions, resulting in a higher profit.

A partial budget analysis can be completed to measure the financial implications of adjusting plant spacing to target specific bin categories and maximize profits. A partial budget analysis is an economic tool that systematically evaluates the costs and benefits of changing a specific practice or technology within a current business operation (Cornelisse 2023). Increasing plant density would increase yield, but it would also increase seed costs, labor cost, and harvest workload. A partial budget analysis would calculate whether higher yield from a higher plant density would still be profitable with the additional input costs. Currently, partial budget analyses exist for other pumpkin management practices, such as organic practices (Brumfield et al. 2000), biodegradable mulches (Galinato et al. 2020), and no tillage (Orzolek et al. 2012); however, there are none for plant spacing and bin yield. By calculating a partial budget analysis of plant spacing, we could measure the profit of planting pumpkins at various densities in North Carolina.

The research objective of this study was to establish a standard fruit size for the commercial pumpkin bin categories medium, large, extra-large, and jumbo. We hypothesized that current sorting practices are not consistent, and that fruit of varying sizes are categorized in the same bin. Additionally, we aimed to correlate plant spacing to the estimated bin category and quantity. We hypothesized that a smaller plant area would result in a greater profit than larger plant area because smaller plant area increases fruit yield per area and would result in a higher commercial bin yield.

Materials and Methods

Research was completed using three steps: a production study that measured the plant spacing effect on fruit size, a commercial bin study that measured fruit size in commercial bins, and an analysis of costs of and profit from different planting size areas.

Production information. The study plot was located at Laurel Springs, NC, USA, at the Upper Mountain Research Station. The study assessed fruit yield for four plant growing areas, 0.9, 1.9, 2.8, and 3.7 m^2, which are equivalent to 10,764, 5382, 3588, and 2691 plants/ha. Each plant spacing was assessed at two row widths, 3.0 and 1.5 m, with the in-row spacing adjusted to meet the specified plant growing area. The 3.0-m row width spacing had in-row measurements of 0.3, 0.6, 0.9, and 1.2 m. The 1.5-m row width spacing had in-row measurements of 0.6, 1.2, 1.8, and 2.4 m. The field had a randomized complete block design with three repetitions in 2020 and four repetitions in 2021. Fertilizer was applied before planting at 112 kg/ha of 0N–0P–41.5K and 329.3 kg/ha of 17N–7.4P–14.1K, and a side dress of 39.2 kg/ha of 15N–6.5P–12.5K was applied 35 d after planting. North Carolina State Cooperative Extension employees at the research station managed weeds and diseases by applying pesticides and hand weeding (Supplemental Tables 1 and 2). No supplemental irrigation was used. There was a one-time harvest on 1 Oct 2020 and on 23 Sep 2021, with 1033 'Kratos' pumpkins (*Cucurbita pepo*) harvested over both years. Mature, blemish-free fruit were measured to determine the weight, length (stem to blossom end), and diameter (the largest distance across the fruit perpendicular to length). The average daily high and low temperatures during the 2020 growing season were 24.0 °C and 14.5 °C (North Carolina Agricultural Research Service State Climate Office of North Carolina 2022). In 2021, these metrics were 24.7 °C and 14.1 °C. Total rain accumulations were 50.0 cm in 2020 and 44.1 cm in 2021.

The production statistics of this study have been reported separately in another *HortScience* publication (Heagy et al. 2023). Additional details regarding the location, field preparation, harvest, and data collection can be found in that study.

Commercial bin information. This was an observational study conducted in 2022 in Jefferson, NC, USA. Pumpkins were provided by commercial producer Sexton Farms, which is located in a 6a plant hardiness zone on Watauga loam soil (lat. 36.406673°N, long. 81.424202°W) (US Department of Agriculture, National Resources Conservation Service 2022). Sexton Farm planted their crop between 23 May and 1 Jun, and mature pumpkins were harvested during the first and second weeks of September. The observational study was completed at the Shatley Farms packing facility (lat. 36.439681°N, long. 81.430202°W), where pumpkin bins were being stored (Jefferson, NC, USA). Pumpkins were packed by Sexton Farm employees into standard 36-inch cardboard bulk bins and sorted into size categories of medium, large, extra-large, and jumbo with the corresponding bin counts of 55 to 65, 40, 30, and 20 fruit per bin. Fruit was sorted by size based on the employees' independent and subjective judgment. This is the standard for the industry (Sexton G, personal communication). Cultivars included, but were not limited to, Hermes (4.55–5.41 kg), Kratos (9.07–13.6 kg) (HM Clause, Davis, CA, USA), Racer Plus (6.35–8.16 kg) (Johnny Seeds, Winslow, ME, USA), and Sweet Baby Jane (6.8–11.3 kg) (Seedway, Hall, NY, USA), which were mixed within bins based on fruit size. Fruit from completed, filled commercial bins were taken out of the packed bins and hand-measured to determine length and diameter using a caliper (Mantax Aluminum caliper; Haglöf Sweden AB, Madison, MS, USA). Three bins of each category were measured and recorded. There were 180 medium, 118 large, 90 extra-large, and 64 jumbo pumpkins. A summary of the treatments from the production and commercial bin study are presented in Table 1. For simplicity when explaining the treatments, plant area sizes have been numbered 1 to 8, and the bin sizes have been numbered 9 to 12.

Pumpkin volumes were calculated based on the ellipsoid equation for volume $V = \frac{4}{3}\pi abc$ where a, b, and c are each a radius on the planes *x*, *y*, and *z* measuring from the surface to the center of the ellipsoid. The diameter measurement was used for the radii *a* and *b*, whereas the length measurement was used for the radii *c*.

For the production analysis, the independent variable was plant spacing and the dependent variables were fruit weight, length, and diameter. For the commercial bin study, the independent variables were fruit weight, length, and diameter, and the dependent variable was the resulting assigned bin category. Statistics were completed using SAS (SAS version 9.4; SAS Institute, Cary, NC, USA) for the analysis of variance and discrimination tests with significance set at 0.05%.

Partial budget analysis. The template for the partial budget analysis was taken from *Penn State Extension Agricultural Alternatives: Sample Watermelon Budget* (Orzolek et al. 2012) and *Watermelon Production Enterprise Budget* (McMinn et al. 2017). Costs for seeds, chemicals, and soil amendments were the prices from suppliers of the Upper Mountain Research Station. These include Harris Seeds (Rochester, NY, USA) and Nutrient Ag Solutions (Saskatoon, SK, Canada). The labor cost in North Carolina in 2023 was $14.91 per hour, which was set by the Adverse Effective Wage Rate (US Department of Labor, Employment and Training Administration 2023). Costs for pallets and bulk bins were taken from online suppliers such as Bulk Bin (Grass Valley, CA, USA). Estimated labor hours, machine hours, and machine operational costs were supplied by a winter squash enterprise budget created by North Carolina Cooperative Extension (unpublished material). Most growers local to the Laurel Springs, NC, USA, area produce their pumpkin crop using no tillage. With this management practice, there is no supplemental irrigation used in the field; therefore, the budget did not include irrigation costs. Additionally, this budget analysis did not consider machine ownership costs.

There are several fixed costs for pumpkin production regardless of plant density, including sowing, spray applications, and fertilizers. Sowing is completed with a vacuum planter, which does not increase machine hours or labor when increasing plant density. Chemicals and fertilizer are a fixed cost because these are applied on a per-area basis; however, high-density planting would create more foliage and denser canopy, which may require more field management. For example, a postemergent spray would have a smaller application timeframe because the denser canopy would prevent pesticide penetration. Additionally, if fertilizer was applied through fertigation, then it may increase with increased plant density if it is calculated on a per-plant basis.

Table 1. A treatment summary for the two studies used for the pumpkin (*Cucurbita pepo*) partial budget analysis. The production study analyzed yield for four plant areas, 0.9, 1.9, 2.8, and 3.7 m^2, at row widths of 3.0 and 1.5 m. The commercial bin study analyzed fruit size for fruit categorized as medium, large, extra-large, and jumbo pumpkins. For simplicity, these data are labeled as treatments 1–12.

Study	Treatment	Plant spacing (m)	Plant area (m^2)	Bin category
Production	1	3.0 × 0.3	0.9	N/A
Production	2	3.0 × 0.6	1.9	N/A
Production	3	3.0 × 0.9	2.8	N/A
Production	4	3.0 × 1.2	3.7	N/A
Production	5	1.5 × 0.6	0.9	N/A
Production	6	1.5 × 1.2	1.9	N/A
Production	7	1.5 × 1.8	2.8	N/A
Production	8	1.5 × 2.4	3.7	N/A
Commercial bin	9	N/A	N/A	Medium
Commercial bin	10	N/A	N/A	Large
Commercial bin	11	N/A	N/A	Extra-large
Commercial bin	12	N/A	N/A	Jumbo

N/A = not applicable.

Variable costs for different plant densities include seed cost, packaging materials, harvesting labor, and harvesting machinery operations. More seeds are required per hectare to grow pumpkins at a higher plant density. As plant quantity increases, fruit production also increases, which would require more labor and packing material to harvest the additional fruit. Furthermore, with increased yield, tractor operational costs and labor would increase because it requires more time to collect and haul fruit away from the field to the packaging facility.

Results and Discussion

Results are presented first as fruit bin size measurements, a suggested standardization to fruit size per bin category, and a partial budget analysis per plant density.

Bin category fruit size. Pumpkins increased in diameter, length, and volume as bin size categories increased from medium to large to extra-large to jumbo (Table 2). Fruit diameter and volume were chosen as metrics to evaluate the fruit size. These were chosen because the diameter showed the most separation in the raw data, whereas volume was a holistic measurement that considered both length and diameter. The mean diameters for the bin categories were 24.5 cm for medium, 28.4 cm for large, 31.5 cm for extra-large, and 35.1 cm for jumbo (Table 2). Additionally, the volumes were 6815 cm^3 for medium, 10,649 cm^3 for large, 14,697 cm^3 for extra-large, and 20,196 cm^3 for jumbo. These results demonstrate separation between diameter and volume for pumpkins that comprise 20-, 30-, 40-, and 55-count bins. The fruit size of these benchmark bin counts could serve as a framework to standardize fruit sizes for each bin category.

These data have outliers, which highlight flaws with the current system of size accounting. Jumbo was the only bin category with volume outliers, which were larger in volume than the normal distribution (Fig. 1). There is not a bin size category larger than jumbo, which means all pumpkins larger than the jumbo bin size range are placed into the jumbo bin by default. Pumpkins larger than the jumbo category are generally a waste of resources because there is no or limited demand or additional income for the increased fruit size among large commercial chain retailers. Medium and large bins had outliers when measuring diameter, but not volume,

Table 2. Average pumpkin (*Cucurbita pepo*) fruit diameter, length, and volume from commercially sorted bins categorized and labeled as medium, large, extra-large, and jumbo. Each fruit size has a corresponding bin count that refers to the approximate number of fruits that will fit into the bin based on fruit size.

Commercially sorted packaging		Fruit measurements		
Bin count	Fruit size	Diam (cm)	Length (cm)	Volume (cm^3)
55–65	Medium	24.5 a[1]	21.4 a	6,815 a
40	Large	28.4 b	25.3 b	10,649 b
30	Extra-large	31.5 c	28.0 c	14,697 c
20	Jumbo	35.1 d	31.0 d	20,196 d

[1] Values within the same column followed by the same letters do not differ significantly ($P \geq 0.05$) according to Tukey's honestly significant difference.

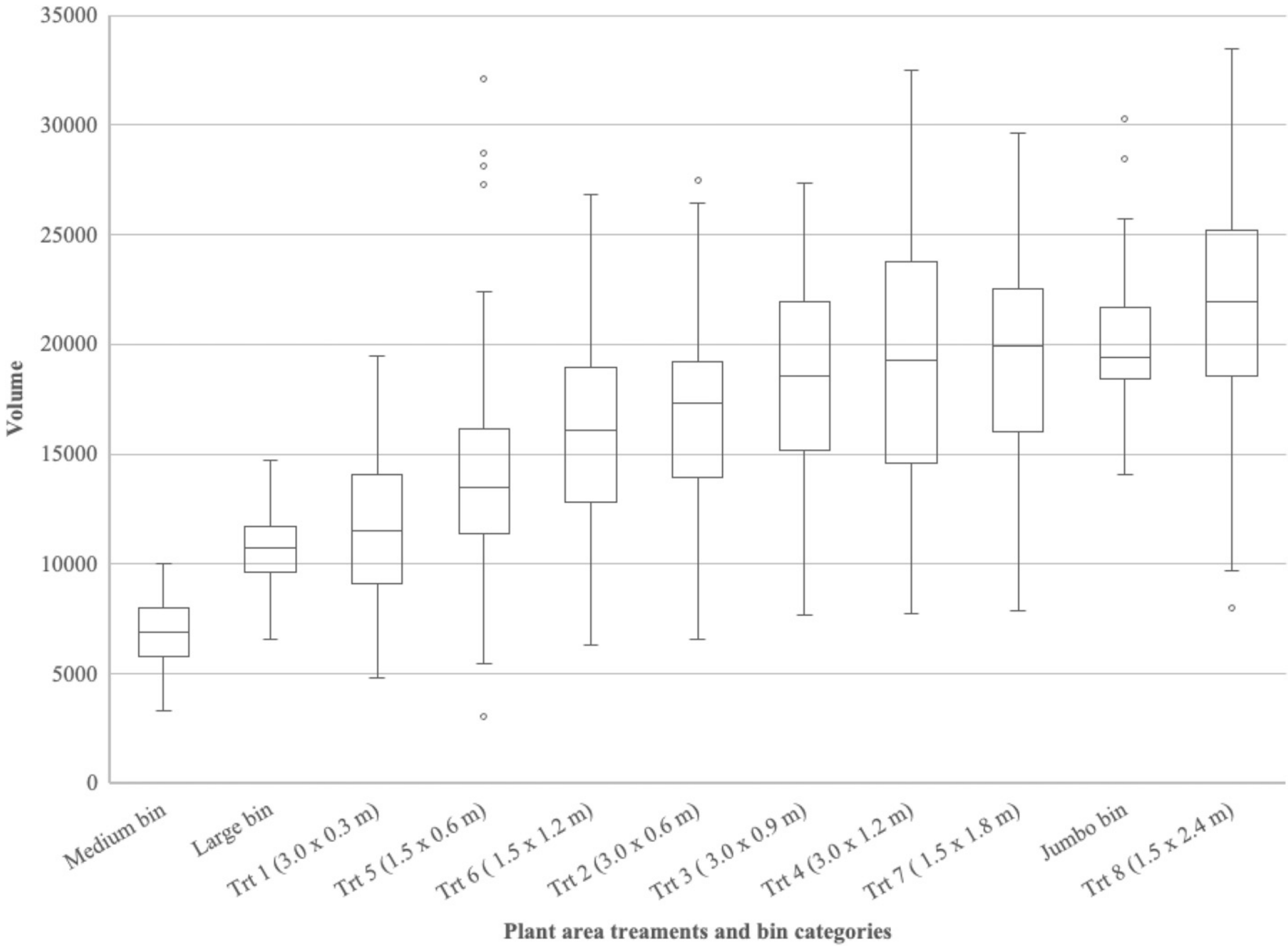

Fig. 1. A comparison of pumpkin volumes (cm^3) from eight plant areas and four commercial bin size categories calculated from pumpkin production and commercial bin data. The eight plant areas include 0.9, 1.9, 2.8, and 3.7 m^2 with a 3.0-m row width (treatments 1–4 respectively) and 1.5-m row width (treatments 5–8, respectively). The four commercial bin size categories include medium, large, extra-large, and jumbo (treatments 9–12, respectively). A treatment summary is provided in Table 1.

indicating that the lengths of these pumpkins negated any diameter abnormality (Fig. 1). This underlines the fact that pumpkins are irregularly shaped fruit, and measuring more than one metric will help accurately represent the overall fruit size. Other commodities, such as cucumbers and sweetpotatoes, follow this philosophy and specify size standards in terms of fruit or root length and diameter (US Department of Agriculture, Agricultural Marketing Service 2005, 2018).

Discriminate analysis of bins. Because diameter, length, and volume were distinct for each size category, a discriminate analysis was conducted to analyze the accuracy of subjectively sorted fruit into each bin category. Medium fruit were correctly categorized 89% of the time. Large fruit were correctly categorized 80% of the time. Extra-large fruit were correctly categorized 64% of the time. Jumbo fruit were correctly categorized 87% of the time (Table 3). These rates averaged to an overall accuracy of 80% for correct placement. For comparison, the watermelon industry size guidelines state that at a specific size range, 5% of the fruit can be under the tolerance and 5% can be over the tolerance, resulting in a total deviation of 10% outside of the size tolerance (US Department of Agriculture, Agricultural Marketing Service 2021). Extra-large had the highest number of misplaced pumpkins, with 21% being placed in a large bin and 14% being place in a jumbo bin. When pumpkins were misplaced, they were misplaced into a neighboring bin size. Considering large and extra-large pumpkins, misplaced pumpkins were sized up 33% of the time and sized down 67% of the time. Medium and jumbo pumpkins were not considered for this metric because misplaced pumpkins could only be sized up or sized down, respectively. The sizes of pumpkin fruit in bin categories are different from one another, but the discriminate analysis showcased how the current system of visually sorting pumpkins is not satisfactory when separating these differences.

Bin size category standards. The sorting of commercial pumpkin bins can be improved by creating a standard fruit size for each bin size category. Fruit volume would be the optimal metric because it measures the overall

Table 3. Discriminant analysis of pumpkins (*Cucurbita pepo*) sorted by size into a commercial bin categorized as medium, large, extra-large, and jumbo. Data were collected at a commercial packing house where fruit were sorted subjectively by employees.

	Number of observations and percent classified into each bin size				
	Medium	Large	Extra-large	Jumbo	Total
Medium	160	20	0	0	180
	88.89%	11.11%	0.00%	0.00%	100.00%
Large	12	94	12	0	118
	10.17%	79.66%	10.17%	0.00%	100.00%
Extra-large	0	19	58	13	90
	0.00%	21.11%	64.44%	14.44%	100.00%
Jumbo	0	0	8	56	64
	0.00%	0.00%	12.50%	87.50%	100.00%
Total	172	133	78	69	452
	38.05%	29.42%	17.26%	15.27%	100.00%

fruit size in terms of length and diameter; however, volume is difficult to measure. Pumpkins are large and heavy. Practically, this makes hand-measuring both the length and diameter of fruit cumbersome and time-consuming. We suggest defining pumpkin bin categories based on fruit weight or by fruit diameter based on growers' harvesting practice. Based on the observed pumpkin bins, fruit volume and weight are highly correlated ($R^2 = 0.94$). This indicates that fruit weight can successfully capture the overall fruit size even with varying pumpkin shapes. Categorizing fruit by weight would be a simple and easily implemented method. This concept is already in place for watermelon, which are sized according to fruit weight (US Department of Agriculture, Agricultural Marketing Service 2021). Because most pumpkin sorting occurs directly in the field in North Carolina, we also suggest defining bin categories by fruit diameter. Pumpkin diameter and pumpkin volume are correlated ($R^2 = 0.93$). At some operations, the ground may be uneven and muddy, which is not conducive to weighing. In these instances, we recommend sorting pumpkins by definitive diameter ranges for each bin category. This could be accomplished by using calipers with each diameter range marked and painted with a different color directly on the caliper ruler. Color markings on the calipers could match the color of the fruit size stickers.

Based on our data, we would recommend weight fruit standards of 4 to 5.99 kg for medium, 6 to 7.74 kg for large, 7.75 to 9.99 kg extra-large, and 10 to 13 kg for jumbo (Table 4). For diameter, these same fruit standards are 23.5 to 26.8 cm for medium, 26.9 to 29.9 cm for large, 30 to 33.6 cm for extra-large, and 33.7 to 35.5 cm for jumbo. These standards were calculated by taking the mean weights and including one standard deviation for each bin category. This method captures a 68% majority of the sample data points. From this point, the standard minimums and maximums were adjusted based on the overlap and/or gaps between neighboring bin categories. Then, the weight ranges were translated into diameter based on the corresponding fruit sizes.

Creating a standard fruit weight for each pumpkin bin category would create a common language for buyers and sellers across the industry. Subjective visual sorting of pumpkins is only 80% effective at sorting fruit and provides merely a description of the product, which is less valuable than a defined standard. Introducing weight standards for pumpkin fruit size would equalize the value for pumpkin bins across the market (Spangler 1956). The US standards for a commodity can be introduced if there is a need or interest among the industry. The process for implementing a new standard involves conducting a study of physical attributes of the commodity, creating a proposal, and posting for public review in the Federal Register (Kader 2002). A standard fruit weight for each bin category would clarify the expectation for growers and allow them to leverage this information to optimize their production.

These recommendations are limited by the sample size of our study. This data set contained 452 pumpkins from one grower with four cultivars. Because there is no current standard, it is highly likely that growers from other regions are categorizing their pumpkins differently by using cultivars and sorting methods not captured here. To build confidence in the pumpkin standards, bin category fruit sizes from additional growers, cultivars, and sorting methods should be surveyed. The standards presented from this research can serve as a starting point for this additional sampling.

Predicting bin size based on plant area. The dependent variables of the production study and the commercial study were compared with the predicted bin category based on plant area. A least-square means test compared the diameter and volume for each plant area to each bin category (Table 5). Four plant area fruit diameters were not different from a bin category fruit diameter. Based on this analysis, we can match the plant area to a bin category by the expected fruit diameter. The remaining four plant areas were different from all bin fruit sizes, signifying that their fruit diameter did not correspond to the fruit diameter from any of the bin categories. In these scenarios, the bin category with the closest diameter to the plant area fruit diameter was selected. This analysis was repeated for volume. For diameter and volume, plant areas of 2.8 and 3.7 m^2 were classified as jumbo, the plant area of 1.9 m^2 was classified as extra-large, and the plant area of 0.9 m^2 was either large or extra-large, depending on the row width. By changing the row width of a 0.9-m^2 plant area from 3.0 m to 1.5 m, the bin category increased from large to extra-large (Table 5). As previously noted, large pumpkins are placed in a 40-count bin and extra-large pumpkins are placed in a 30-count bin. If different row widths are at parity for fruit quantity, then the 1.5-m row width would fill more bins simply by being categorized as extra-large rather than large. This is because only 30 extra-large pumpkins are needed to fill a bin, whereas 40 large pumpkins are needed to fill a bin. Reiners and Riggs (1999) reported increased fruit quantity by reducing the row width from 3.6 to 1.8 m, suggesting an even wider difference between the row width bin quantities. Both plant areas of 2.8 and 3.7 m^2 produced a jumbo pumpkin. This means that there is no increased fruit size by increasing the plant area to more than 2.8 m^2. Several studies indicate that fruit quantity decreases with the increased plant area (El-Sayed et al. 2011; Reiners and Riggs 1999; Weiner 1990). The 2.8-m^2 plant area would have higher economical returns compared with the 3.7-m^2 plant area because both areas produce jumbo pumpkins and the 2.8-m^2 plant area would have more fruit per area.

Some of the pumpkin volumes from the production study were outside of the bounds of the categorized bin volumes, and vice versa. The fruit volume for the 3.7-m^2 plant area with a 1.5-m row width was 21,399 cm^3 which was larger than the mean fruit volume for jumbo pumpkins at 20,196 cm^3. This indicates that a plant area of 3.7 m^2 produces pumpkins larger than the commercial bin range. None of the pumpkins from the production study was categorized as a medium pumpkin. The smallest plant area of 0.9 m^2 produced a large pumpkin. Because fruit size decreases with the decreased plant area (Brinen et al. 1979, El-Sayed et al. 2011, Reiners and Riggs 1997), a smaller plant area would be required to grow a medium 'Kratos' pumpkin. Because 0.9 m^2 is already below the recommended plant area, switching to another cultivar that produces smaller fruit may be more advantageous (Kemble et al. 2022). Without medium pumpkins in this study, we could not provide plant area recommendations for this bin category. This

Table 4. Recommended individual fruit weight and diameter standards for pumpkin (*Cucurbita pepo*) commercial bin size categories of medium, large, extra-large, and jumbo. Currently, there are no industry standards for pumpkin fruit size and the corresponding bin size categories.

	Recommended bin ranges			
	Medium	Large	Extra-large	Jumbo
Minimum weight (kg)	4.00	6.00	7.75	10.00
Maximum weight (kg)	5.90	7.74	9.90	13.00
Minimum diameter (cm)	23.50	26.90	30.00	33.70
Maximum diameter (cm)	26.80	29.90	33.60	35.50

Table 5. Predicted bin categorization of commercial pumpkin (*Cucurbita pepo*) fruit. This prediction is based on plant area and row width and the consequent estimated fruit diameter and volume. These predictions were compared with the fruit diameter and volume of fruit from commercial pumpkin bin size categories of medium, large, extra-large, and jumbo.

Production study treatments		Predicted bin category based on fruit size			
Plant area	Row width	Diam	*P* value	Volume	*P* value
0.9	3.0	Large	0.8045	Large	0.0127[i]
1.9	3.0	Extra-large	0.0328[i]	Extra-large	0.0001[i]
2.8	3.0	Jumbo	0.0004[i]	Jumbo	0.0010[i]
3.7	3.0	Jumbo	0.0112[i]	Jumbo	0.1771
0.9	1.5	Extra-large	<0.0001[i]	Extra-large	0.0064[i]
1.9	1.5	Extra-large	0.3771	Extra-large	0.0210[i]
2.8	1.5	Jumbo	0.1100	Jumbo	0.3012
3.7	1.5	Jumbo	0.6058	Jumbo	0.0776

[i] Indicates that plant area fruit size and bin category fruit differed significantly from one another according to Tukey's honestly significant difference.

was a limitation of this study. Further studies are required to provide this information.

Partial budget analysis. Fixed costs for pumpkin production comprise field preparation, cultivation, field maintenance, totaling $3134/ha (Table 6). Because this partial budget analysis was per hectare, all costs that were on a per-area basis are a fixed cost. Field preparation is estimated to cost $990/ha and includes soil testing, preemergence, lime, and preplant fertilizer. During the growing season, the main input costs are pesticide applications. Labor costs for planting and field maintenance would remain a fixed cost at $777/ha. Finally, estimated machinery operation costs, including a 50-horsepower tractor, plow, boom sprayer, and vacuum planter, would cost $216/ha.

Estimated fruit size and fruit quantity from the production study allow us to estimate the bin category and bin quantity for each plant area (Table 7). The plant areas of 3.7, 2.8, 1.9, and 0.9 m^2 are equivalent to plant densities of 2691, 3588, 5382, and 10,764 plants/ha, respectively. As stated, as the plant area decreases, the fruit number per hectare increases and fruit size decreases. We provide only the 1.5-m row width to streamline the manuscript and estimate the bin category and quantity for each plant area. We also used the 1.5-m rather than 3.0-m between-row spacing because the closer spacing was more productive. Using the 1.5-m row width, the plant areas of 3.7 and 2.8 m^2, on average, produce jumbo fruit, and the plant areas of 1.9 and 0.9 m^2, on average, produce extra-large fruit. Jumbo pumpkins pack 20 fruit per bin, whereas extra-large pumpkins pack 30 fruit per bin. From the 2021 production study, plant areas of 0.9, 1.9, 2.8, and 3.7 m^2 produced 9149, 7097, 5046, and 4676 fruit/ha, respectively. Keeping the same plant area order, the projected bin yields were 305 extra-large bins, 237 extra-large bins, 252 jumbo bins, and 234 jumbo bins. The hectare yields were calculated using small trial plots, which may negate the effect of economies of scale and was a limitation of this study.

The variable costs for plant area include seed costs, harvest packaging material, harvest labor, and machine operations (Table 8). The cost for seed increased from $340 to $1358 when decreasing the plant area from 3.7 to 0.9 m^2. Because decreased plant area leads to increased fruit yield, more bins and pallets are required for harvest with higher plant densities. These packaging costs increased by $2676 from the lowest to the highest plant density. With higher fruit yield, labor costs will increase because more time and workers are required to harvest the additional fruit. Furthermore, machine operation costs will increase because more hours are required to collect, harvest, and haul pumpkins out of the field. Overall, variable costs start at $10,359/ha with the plant area of 3.7 m^2, with a density of 2691 plants/ha, and increase to $17,652/ha for the plant area of 0.9 m^2, with a density of 10,764 plants/ha.

Pumpkins were sold at an average price of $190 per bin across all bin size categories in 2022 (US Department of Agriculture, Economic Research Service 2022). From the fixed costs, variable costs, and yield estimates, the highest profiting plant area was 0.9 m^2, or 10,765 plants/ha, with a profit of $37,163/ha (Table 9). The lowest profiting plant area was 1.9 m^2, or 5382 plants/ha, with a profit of $29,885/ha. This is a difference of $7278/ha, or a 24% profit increase. During this specific comparison, the difference in profit was strictly associated with fruit quantity. Both plant areas produce fruit that would be categorized as extra-large according to the analysis predicting fruit size based on plant area. From that same analysis, the results showed that the 0.9-m^2 plant area produces more individual fruit than the 1.9-m^2 plant area. This translates into 68 more extra-large category commercial bins per hectare with the 0.9-m^2 plant area compared with 1.9 m^2. It is economically beneficial for growers to maximize fruit quantity within plant areas producing the same categorical fruit size.

According to another example, the 3.7-m^2 plant area produced 234 jumbo category commercial bins, with a profit of $30,967/ha. In contrast, the 0.9-m^2 plant area produced 305 extra-large bins, with a profit of $37,163/ha (Table 7). This illustrates that growing larger pumpkins does not always lead to higher profits. Instead, profit is based on a combination of fruit size, categorical bin count, and fruit quantity per hectare. From this study, a grower can attain an addition profit of $6196/ha by producing extra-large pumpkins in a smaller plant area rather than jumbo pumpkins in a larger plant area. If growers are producing jumbo pumpkins, then they should consider reducing the plant area for their next growing season to avoid wasting additional inputs.

Growers can use this partial budget to maximize their profit within the constraints of their operations. Equipment, land, or storage facility may limit growers' production to a certain row width, total plant area, or bin quantity. This partial budget analysis will help producers adjust other factors within their operations to maximize profit strategically through bin category and quantity.

Conclusions

Commercial practices of visually sorting pumpkins into categorical bin sizes are currently

Table 6. Fixed costs for pumpkin (*Cucurbita pepo*) production per hectare at densities of 2691, 3588, 5382, and 10,746 plants/ha.

Item	Unit	Quantity	Item cost ($)	Total costs ($)
Field preparation and cultivation				
Soil test	Test	1	25.00	25.00
Lime	Tons	1.85	36.00	66.60
Preplant fertilizer: 10–10–10	Tons	1.11	610.00	677.10
Preemergence herbicide				
Curbit 3EC	Liter	2.33	12.19	28.40
Gramoxone Max	Liter	1.16	31.94	37.05
Roundup Weathermax	Liter	1.16	31.94	37.05
Command 4EC	Liter	1.16	17.03	19.75
Select 2EC	Liter	1.16	85.17	98.80
Field maintenance				
Fertilizer — side dress	Tons	0.13	610.00	79.30
Fungicides	Application	8	74.10	592.80
Insecticides	Application	8	37.05	296.40
Machinery operations				
Field preparation and cultivation — tractor	Hours/ha	28.4	4.50	127.80
Field preparation and cultivation — plow 3–16 inches	Hours/ha	4.9	2.00	9.80
Field preparation and cultivation — planter	Hours/ha	2.47	1.50	3.71
Field maintenance — tractor	Hours/ha	13	4.50	58.50
Field maintenance — boom sprayer	Hours/ha	11.1	1.50	16.65
Labor				
Field preparation and cultivation	Hours	15.07	14.91	224.69
Field maintenance — tractor	Hours	37.05	14.91	552.42
Other				
Crop insurance	Hectare	1	182.65	182.65
Total fixed costs				**3,134.57**

Table 7. Bin yield estimation for commercial pumpkin (*Cucurbita pepo*) production based on plant density. Yield was calculated based on predicted individual fruit size and the subsequent bin size category (medium, large, extra-large, jumbo), the bin count, and the expected fruit/ha. Plant densities analyzed were 2691, 3588, 5382, and 10,746 plants/ha with a 1.5-m row width.

		Plant density (plants/ha)			
		2691	3588	5382	10,764
Yield estimation	Plant area (m^2)	3.7	2.8	1.9	0.9
Bin category based on individual fruit size		Jumbo	Jumbo	Extra-large	Extra-large
Fruit/bin (bin count)		20	20	30	30
Fruit number/ha		4676	5046	7097	9149
Expected bin/ha		234	252	237	305

Table 8. Variable costs for pumpkin (*Cucurbita pepo*) production per hectare at densities of 2691, 3588, 5382, and 10,746 plants/ha.

Item	Unit	Quantity	Item cost ($)	Cost ($/ha) by plant density (plants/ha)			
				2691	3588	5382	10,764
Field preparation, cultivation							
Treated seeds	Thousand	1	126.17	339.52	452.70	679.05	1,358.22
Harvest							
Fiberboard bins	Case	42	1,079.00	6,011.46	6,473.88	6,088.53	7,835.45
Pallets — repaired grade A	Pallet	234 (2,691 plants/ha) 252 (3,588 plants/ha) 237 (5,382 plants/ha) 305 (10,764 plants/ha)	12.00	2,808.00	3,024.00	2,844.00	3,660.00
Labor: harvesting	Hours	53 h (2,691 plants/ha) 70 h (3,588 plants/ha) 105 h (5,382 plants/ha) 211 h (10,764 plants/ha)	14.91	786.72	1,048.96	1,573.44	3,147.18
Labor: hauling	Hours	23 h (2,691 plants/ha) 30 h (3,588 plants/ha) 45 h (5,382 plants/ha) 90 h (10,764 plants/ha)	14.91	337.17	449.56	674.33	1,348.79
Machinery operations							
Harvest and hauling — tractor	Hours	16 h (2,691 plants/ha) 21 h (3,588 plants/ha) 32 h (5,382 plants/ha) 64 h (10,764 plants/ha)	4.50	71.65	95.54	143.31	286.64
Wagons, trailers	Hours	16 h (2,691 plants/ha) 21 h (3,588 plants/ha) 32 h (5,382 plants/ha) 64 h (10,764 plants/ha)	0.25	3.98	5.31	7.96	15.92
Total variable costs				10,358.50	11,549.95	12,010.62	17,652.20

Table 9. Summary of income, total costs, and net returns for commercial pumpkin (*Cucurbita pepo*) production per hectare by densities of 2691, 3588, 5382, and 10,746 plants/ha.

Item	Price ($)	Income by plant density (plants/ha)			
		2691	3588	5382	10,764
Income					
Expected bin quantity[i]		234	252	237	305
Categorized commercial bin	190.00	44,460.00	47,880.00	45,030.00	57,950.00
Total costs (fixed + variable)[ii]		13,492.97	14,684.42	15,145.09	20,786.67
Net returns		30,967.03	33,195.58	29,884.91	37,163.33

[i] Please refer to Table 7 for expected bin quantity calculations.

[ii] Please refer to Tables 6 and 8 for fixed and variable cost calculations.

80% effective. Standardizing fruit size for each bin category would create a common language among buyer and sellers. We suggest using a defined weight or diameter range for each bin category. These methods were chosen because they would be easy to implement with current harvest practices and replicate across the industry. A limitation of the commercial bin study is the sample size of one grower that used one sorting practice and only a few cultivars. To create a more robust recommendation, additional data of different growers, sorting practices, and cultivars should be collected.

Growers can use these standard fruit sizes to predict yield in terms of bin category and quantity based on their plant area. Data from the production study estimated that plant areas of 0.9 and 1.9 m^2 produce extra-large pumpkins, whereas 2.8 and 3.7 m^2 produce jumbo pumpkins. As stated, a limitation of this study was that the fruit size range from the production study did not align with the fruit size range from the commercial bin study. With this gap, the bin sizes of medium and large cannot be correlated to a plant area while using a 3.0-m row width. Further research with other plant areas will have to be conducted to predict a plant area for growing medium and large pumpkins.

By completing a partial budget analysis of plant area, growers can maximize profits on a per-hectare basis by growing extra-large bins with a 0.9-m^2 plant area and profit of $36,890/ha. Growers can use this analysis to make an informed decision regarding plant density by understanding the associated variable costs and predicted income at each plant density. Through these suggestions, pumpkin producers can maximize their production and their profits.

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