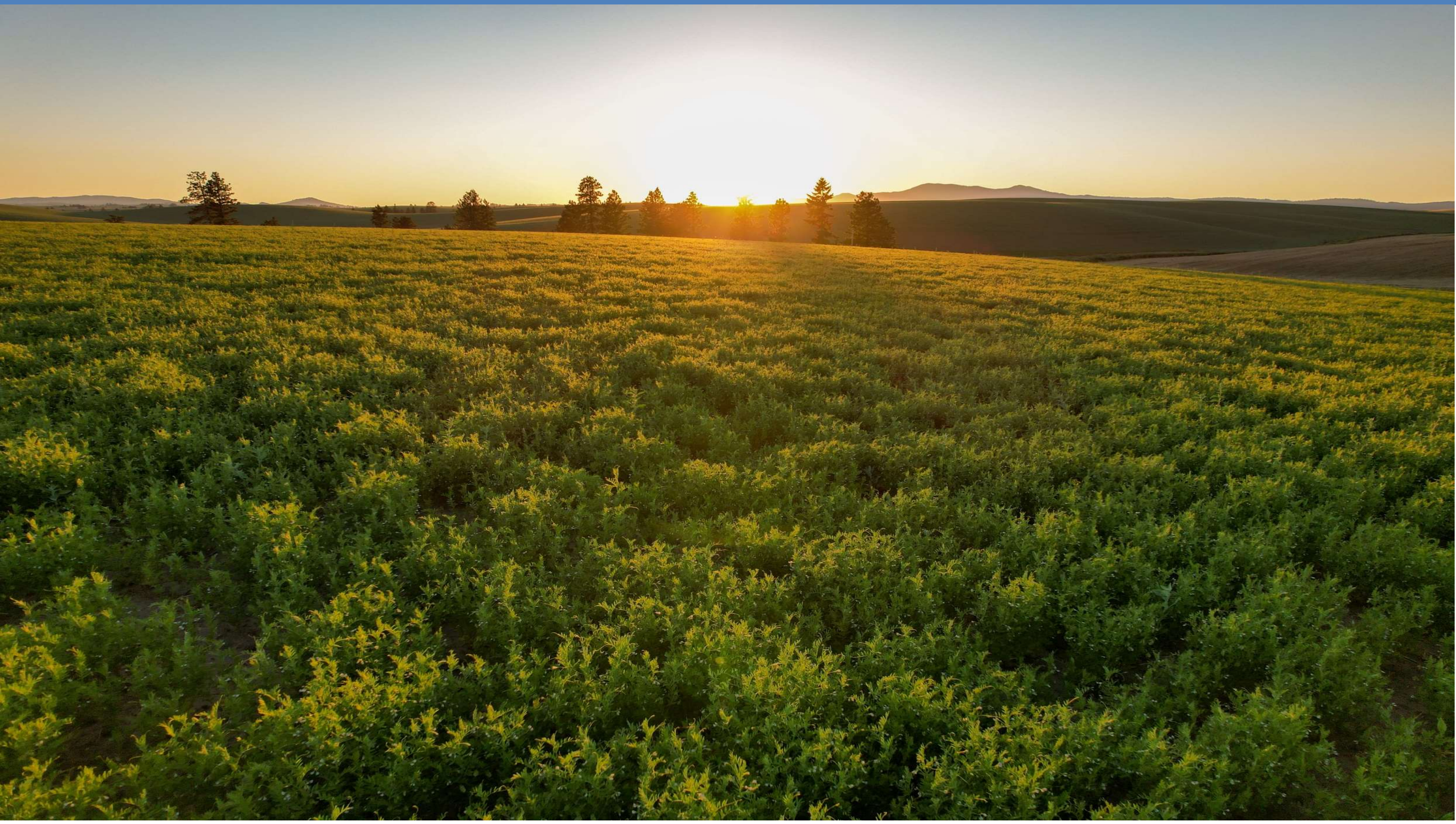
2023 U.S. Pulse Quality Survey



Northern Pulse Growers Association

USA Dry Pea & Lentil Council

Contents

2023 Overview and Author's Comments

Summary Points

1. The 2023 pulse quality report represents the 16th variation of a pulse quality evaluation started by the Northern Crops Institute in 2008. The data in this report includes both 5- and 10-year mean data where available. The 10-year mean represents a long-term assessment of quality.
2. Data from 173 samples received from major US pulse growing regions were evaluated. Mixed growing conditions (i.e., both dry and wet) had a significant impact on sample collection in 2023.
3. Six functionality tests and a RVA gel firmness value were reported for the second time in 2023.
4. Significant impacts on protein (higher percentage) and starch (lower percentage) were observed in peas and chickpeas.
5. Chickpea had lower 1000-seed weights and percentage retention on a 22/64-inch sieve in 2023. Due in part to the evaluation of more small-seeded chickpeas cultivars.
6. Cold paste viscosity was lower for chickpea compared to previous years and may have contributed to the lower gel firmness in 2023 than in 2022.
7. Lentils had lower pasting viscosities compared to long-term mean values which indicates thinner pastes resulted in 2023. However, gel firmness was higher than values from 2022.

This report provides a summary of the 2023 pulse crop quality for dry pea, lentil and chickpea grown commercially in the USA. In 2023, a total of 173 pulse samples were collected from the major US pulse growing regions. The seeds evaluated included 48 dry pea, 47 lentil, and 78 chickpea samples, which were acquired from pulses growers and industry representatives in pulse growing areas in Idaho, Montana, North Dakota, Oregon, South Dakota, and Washington.

According to the USDA National Agricultural Statistics Service, pulse harvested acres and estimated total production for 2023 was 1.82 million acres and approximately 1.5 million metric tons, respectively. Pulse acres in 2023 were higher compared to 2020 - 2022 but lower than acres harvested in 2019. Pea and chickpea harvested acres and production were higher in 2023 compared to 2020-2022 while lentil harvested acres and production were lower in 2023 compared to 2022 and 2021 but more than 2019 and 2020.

The quality is grouped into three main categories, which include proximate composition, physical parameters, and functional characteristics. The canning quality was also a separate category. Proximate quality parameters include ash, fat, moisture, protein, and total starch content. Water hydration capacity, percentage unhydrated seeds, swelling capacity, cooked firmness, test weight, 1000 seed weight, size distribution and color represent the physical parameters. The pasting characteristics represent the functional characteristics of the pulses. In addition, six new functionality tests were completed in 2022. These included emulsion activity and stability, foaming capacity and stability, water holding capacity and oil holding capacity, which were run again in 2023.

Results from the proximate (e.g., moisture, protein) composition analyses indicated that results were mixed and did not follow closely the results from any one previous year. However, some results were comparable to 5- and 10-year mean data.

In general, peas, lentils, and chickpeas from 2023 had the same or lower moisture contents compared to pulses from previous crop years. Peas and chickpeas had moisture contents lower than the 5-year mean moisture values. However, the moisture contents of the pulses from 2023 tended to match the 10-year mean moisture contents of their respective pulse crop. In contrast, lentil moisture content in 2023 was slightly higher than the 5- and 10-year mean values. Collectively, the data suggests that the long-term moisture is a good guide to predicting moisture content of a pulse. The total starch contents of all three pulses were significantly lower in 2023 compared to the 5- and 10-year mean starch content. The total starch percentages in lentils from 2023 was comparable to starch content in lentils from 2022. Total starch in peas grown in 2023 was lower than peas from 2019-2022. The chickpea from 2023 had mean total starch content that was similar to peas from 2019-2021. The winter pea class had total starch that was lower than winter peas from previous production years except winter peas from 2022. The three lentil classes had lower mean total starch contents in 2023 compared to their respective 5- and 10-year mean values. The mean protein content in peas from 2023 was higher than the 5- and 10-year mean protein contents. The protein content of green peas did not match the protein contents from any previous year. In contrast, the protein content in yellow peas from 2023 was comparable to yellow peas from 2020 and the 5- and 10-year mean values. Winter peas from 2023 most closely matched winter peas from 2021. Lentils from 2023 had protein contents similar to lentils from 2019. The protein content in the 2023 chickpeas was higher than both the 5- and 10-year mean values. Collectively, the protein data from recent years supports higher protein compared to the long term mean value with only a few exceptions. The fat contents of the pulses evaluated were within the range reported in the literature. The mean fat contents of peas and lentils from 2023 tended to be lower than their respective crops from previous years except 2021. In contrast, the mean fat content of chickpeas from 2023 was lower than the mean fat contents of chickpeas from all previous years.

The mean test weight, water holding capacity, swelling capacity and cooked firmness of peas matched the 5- and 10-year mean values while 1000 seed weight was lower than the long-term mean. The values of the physical parameters of lentils were the same or higher compared to their 5- or 10-year mean values. Swelling capacity was notably higher for lentil in 2023. In general, physical parameter values were the same or slightly less than the 5- or 10-year mean values for chickpeas. Notably, the chickpea mean test weight and 1000 seed weight were lower than the 5- and 10-year mean values. The large chickpea such as Nash had a 1000 seed weight of 526 and 530 in 2023 and 2020, respectively. This suggests that only minor differences in seed size existed for the same cultivar over different years and that the considerable number of small chickpeas cultivars that were included in the survey likely contributed to the lower 1000 seed weight. A size distribution analysis of chickpeas indicated a smaller seed size for chickpeas from 2022. The Dylan chickpea cultivar had the highest percentage (88.2%) of seeds retained on a 22/64-inch sieve in 2023. Overall, the chickpea from 2023 had a lower percentage of seeds being retained on the 22/64- and 20/64-inch sieves compared to other years. However, the results were impacted by the Marvel and Kasin cultivars, which only 1% of their seeds were retained on the 22/64-inch sieve. Thus, making assumptions about seed size should be avoided.

The physical parameter values of winter peas were similar to values obtained in peas from 2022. However, green and yellow peas tended not to be like previous crop years. Unlike red lentil, green and Spanish brown lentils from 2023 had similar physical parameter values as lentils from 2022 for their respective color classes.

The color of the green and Spanish brown peas in 2023 were lighter than peas that made up the 5- and 10-year mean lightness (L*). Overall, peas from 2023 most closely matched peas harvested in 2020. The color difference values of dry peas vs. soaked peas from 2023 were higher than peas from other harvest years. The increased yellowness was the main reason for the higher color differences in both the green and yellow peas from previous years. The color tended to be lighter for green and Spanish brown lentils whereas the red lentils were darker than lentils from previous years. This might be the result of the samples having higher yellowness values (i.e., b* value) compared to previous years. The 2023 chickpea crop had slightly higher lightness values compared to the 5-year mean but had L* values less than the 10-year mean L* value. Overall, the color difference between dry and soaked chickpea was lower than the 5-year mean value.

The starch pasting properties for the 2023 peas, lentils and chickpeas were significantly lower compared to the 5- and 10-mean values. The paste that resulted from samples were less viscous than the paste of samples from other crop years. New in 2022 was the addition of a RVA gel firmness test. This test was repeated again in 2023. Green and yellow peas had gel firmness values that were higher in samples from 2023 compared to 2022. In contrast, winter peas had lower gel firmness values in 2023. The Spanish brown lentils had significantly lower gel firmness values in 2023 compared to 2022. However, the 2023 green lentils had comparable gel firmness values to green lentils from 2022. Chickpea followed the same trend as the Spanish brown lentils. Other functionality tests new in 2022 and again repeated in 2023 showed that emulsion activity and stability did not differ significantly among the pulse samples. The foaming capacity was lower in 2023 for pea and lentils compared to samples from 2022. In contrast, chickpeas had comparable foaming capacities in 2023 and 2022. However, foam stability was either greater than or the same for all pulses from 2023 compared to pulses from 2022. The oil holding capacities of all pulses were lower in 2023 compared to values from pulses grown in 2022. However, no differences in water holding capacity were observed between pulses from 2022 and 2023, regardless of pulse type.

Overall, the canning quality data of peas from 2023 supports less rehydration of the peas and greater canned firmness. The water hydration capacity of canned peas in 2023 was comparable to the 5-year mean values. Canning firmness was significantly higher (i.e., firmer) in 2023 compared to peas from 2020 and 2022 and the 5-year mean value. Chickpeas from 2023 had hydration capacity and swelling capacity greater than canned chickpeas from other years except 2019. The mean canned firmness of chickpea from 2023 was 8.2 N/g, which is lower than the 5-year mean canned firmness value.

The focus of the pulse program is the quality evaluation and utilization of pulses as food and food ingredients. The mission of the Pulse Quality Program is to provide industry, academic and government personnel with readily accessible data on pulse quality and to provide science-based evidence for the utilization of pulses as whole food and as ingredients in food products. Thus, I welcome any thoughts, comments, and suggestions regarding the report. If a quality trait is of interest, please reach out to me. I would like to thank the USA pulse producers for their support of this survey.

Sincerely,

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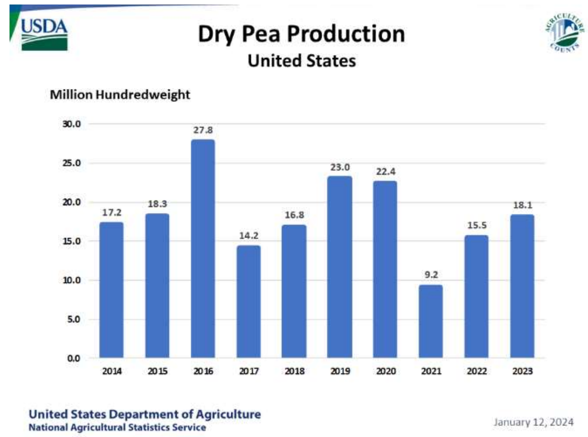
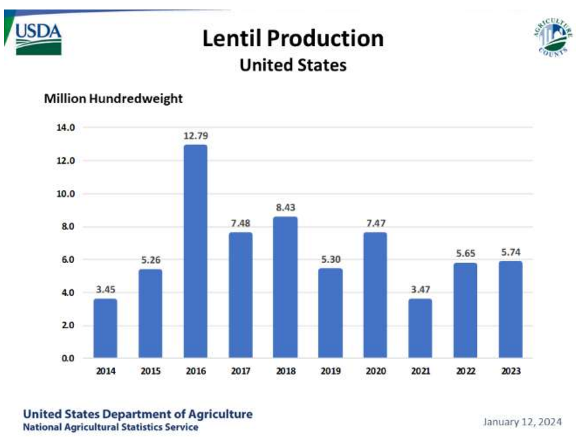
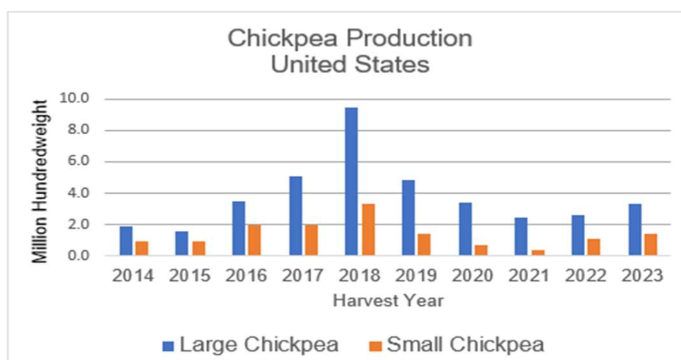
Pulse Production



The Northern Plains region and Pacific Northwest are the largest pulse producing areas within the USA. US pulse harvested acreage in 2023 was 1,823,200 (Table 1), which was approximately 22 and 90 thousand more acres than in 2022 and 2021, respectively. Total US pulse production (Metric Tons (MT)) in 2023 is estimated to be 1,450,399 which is up significantly from the 1,050,838 and 668,466 produced in 2022 and 2021, respectively (Table 1). The favorable conditions affecting some of the pulse growing regions likely contributed to the higher production compared to the previous crop years (2020-2022) that had significant drought. The UDSA estimated that the dry pea acreage was 941,000, which was up from 862,000 and 834,000 from 2022 and 2021, respectively (Table 1). Pea production (918,805 MT) was comparable to the production of 941,571 MT in 2020 but significantly more than in 2021 and 2022 (Table 1). The long-term production shows that the 18.1 million 100-weight of peas produced matched the 2014 and 2015 levels.



Lentil acreage was 523,000 in 2023. This value was less than acres harvest in 2022 but more acres from previous years (Table 1). Lentil production in 2023 was 291,705 MT which is higher than the 248,977 MT produced in 2022, and nearly doubled the 2021 production of 150,912 MT. The USDA estimate of 5.74 million 100-weight of lentil matches closely with the 2019 and 2022 production levels but not those from 2016-2018. Chickpea harvested acres (359,200) in 2023 was slightly above the 2021 production of 351,000 acres. Production was estimated at 239,889 MT, which is significantly higher than the production from previous years except 2019 (Table 1). Furthermore, the production of large chickpeas more than doubled the production of small chickpeas. The higher production of pulses supports an increase in yields per acres.



The drought experienced in some parts of the growing region in 2021 had a significant and primary role in the low production of the pulse crops compared to 2023. The yield for dry pea was 1922 lbs./acre in 2023, which is up slightly from 1751 lbs./acre in 2022. Lentil yield (1098 lbs./acre) was up from 900 lbs./acre in 2022 and 606 lbs./acre in 2021. However, this value is still lower than the 2020 yield of 1,338 lbs./acre. Like peas and lentils, chickpea yield (~1272 lbs./acre) was higher than the value (1100 lbs./acre) from the 2022 harvest and significantly higher from the low (815 lbs./acre) for the chickpea crop in 2021. In 2023, less drought persisted in much of the growing region compared to previous growing season and may account for the higher production of pulses.

Table 1. United States pulses acreage and production summary for 2019-2023.

	2023		2022		2021		2020		2019	
Crop	Acreage*	Production#	Acreage*	Production#	Acreage*	Production#	Acreage	Production#	Acreage	Production#
Dry Peas	941,000	918,805	862,000	684,562	834,000	387,780	919,000	941,571	1,052,000	1,135,229
Lentil	523,000	291,705	602,000	248,977	549,000	150,912	510,000	230,881	431,000	273,723
Chickpea	359,200	239,889	341,900	117,299	351,000	129,774	250,800	185,386	404,000	316,854
Total	1,823,200	1,450,399	1,805,900	1,050,838	1,734,000	668,466	1,679,800	1,357,838	1,887,000	1,725,806

*Acreage = Acres Harvested, #Production = Metric Tons, Source: USDA NASS (2024)/ US Dry Pea and Lentil Council

Laboratory Methods Used to Measure Pulse Quality

Where applicable, standard methods were followed for the determination of each pulse quality attribute in 2023 (Table 2). For most analyses, data is provided on data collected between 2019 and 2023. The data is reported as a range, mean and standard deviation (SD) for the 2023 harvest year while preceding years were provided as a means plus SD. Data on cultivars was reported only for the 2023 harvest years and no comparisons were made in the tables to cultivars from the previous year. A summary of the testing methods can be found in table 2. Further information of the testing methods is provided below.

- Moisture content is the quantity of water (i.e., moisture) present in a sample and is expressed as a percentage. Moisture content is an important indicator of pulse seed handling and storability. Pulse crops are recommended for harvest at 13-14% moisture. At lower moisture levels, the seeds are prone to mechanical damage such as fracturing. Pulses with higher moisture levels are more susceptible to enzymatic activity and microbial growth, which reduce quality and increase food safety risks.
- Pulses are rich in protein, which ranges from 20 to 30% depending on the growing location, cultivar, and year. Pulses are low in sulfur-containing amino acids but high in lysine, an essential amino acid for human health. Protein content is the quantity of protein present in a sample and is expressed as a percentage.
- The fat (i.e., lipid) content is the quantity of fat present in the pulse. Usually, peas and lentils have fat contents under 3% while chickpea contain 5-8%.
- Ash content is the quantity of ash present in a sample and is expressed as a percentage. Ash is an indicator of minerals. Higher ash content indicates higher amounts of minerals such as iron, zinc, and selenium.
- Total starch is a measure of the quantity of starch present in a sample and is expressed as a percentage. Starch is responsible for a significant part of the pulse functionality such as gel formation and viscosity enhancement. Enzymatic hydrolysis is the basis for the starch determination. Starch functionality is measured using the RVA instrument. Pulses show a type C pasting profile, which is represented by a minimally definable pasting peak, a small breakdown in viscosity and high final peak viscosity. This type of starch is ideal for glass noodle production.
- Test weight and 1000 seed weight are indicators of seed density, size, shape, and milling yield. Each pulse crop has its own market preference based on color, seed size, and shape. A grain analysis computer is used to determine test weight in lbs./bu.
- Water hydration capacity, percentage unhydrated seeds, and swelling capacity are physical characteristics of pulses that relate to the ability of the pulse to re-hydrate. The swelling capacity relates to the increased size of the pulse as a result of rehydration. Cooking firmness provides information on the texture (i.e., firmness) of the pulse after a cooking process. The data obtained can be used to predict how a pulse might change during cooking and canning processes.
- Color analysis is provided as L*, a* and b* values. Color analysis is important as it provides information about general pulse color and color stability during processing. Color difference is used specifically to indicate how a process affects color. In this report, a color difference between pre- and post-soaked pulses was determined.
    - “L*” represents the lightness on a scale where 100 is considered a perfect white and 0 for black. Pulses such as chickpeas and yellow peas typically have higher L* values than green or red pulses. The “a*” value represents positive for redness and negative for green and “b*” represents positive for yellow, negative for blue and zero for gray. A pulse with a higher positive “b*” value would be indicative of a yellow pulse while a higher “a*” value represents a pulse with a red-like hue, thus brown pulses have a higher red value than a yellow pulse. Green pulses have negative “a*” values and thus the greater the negative value, the greener the pulse.
- Canning quality evaluation. This evaluation serves as an Indicator of pulse quality after a canning process and a three-week storage. The information allows for a relative difference in quality to be established following a canning process that used a brine solution containing calcium chloride.
- The functionality test includes emulsion activity and stability, foaming capacity and stability, water holding capacity and oil holding capacity.
    - Emulsions are a heterogeneous combination or dispersion of two or more immiscible liquids, usually oil and water, which are formed with the aid of mechanical agitation. Stability of an emulsion is simply a gravitational separation of the two primary phases of a mixture.
    - Foams are dispersion of gas bubbles in a liquid or solid phase. Foaming capacity is the amount of interfacial area that can be created by whipping the flour. Foam stability is defined as the time needed to lose 50% of either liquid or volume of foam. These properties can be important for products such as cakes.
    - Water holding capacity and oil holding capacity are measures that allow for the determination of the amount of water or oil that can bind to the flour. This information is important because it allows product developers to identify how much water or oil that may be taken up by flour and thus allow them to adjust formulations as needed.

Table 2. Quality attribute, analytical method, and remarks for analyses conducted for the 2023 pulse quality survey.

Quality Attribute	Method	Remarks
1. Moisture (%)	AACC Approved Method of Analysis, Method 44-15.02	Indicator of post-harvest stability, milling yield and general processing requirements.
2. Protein (%)	AACC Approved Method of Analysis, Method 46-30.01	Indicator of nutritional quality and amount of protein available for recovery.
3. Ash (%)	AACC Approved Method of Analysis, Methods 08-01.01	Indicator of total non-specific mineral content.
4. Total starch (%)	AACC Approved Method of Analysis, Method 76-13.01	Indicator of nutritional quality and amount of starch available for recovery.
5. Fat (Lipid)	AOCS Method Ba 3-38	Indicator of nutritional quality as related to the amount of fat in the samples.
6. Test weight (lb/bu)	AACC Approved Method of Analysis, Method 55-10.01	Indicator of sample density, size, and shape.
7. 1000 seed weight (g)	100-kernel sample weight times 10	Indicator of grain size and milling yield.
8. Chickpea Size Determination	Four samples of 250 seeds of chickpea were placed on a series of sieves (22/64", 20/64", 18/64") and rotated. The number of seed retain on each sieve was determined and reported as % of seed retained.	Indication of the size distribution within a sample of chickpea.
9. Water hydration capacity (%)	AACC Approved Method of Analysis, Method 57-12.02	Indicator of cooking and canning behavior.
10. Unhydrated seed (%)	AACC Approved Method of Analysis, Method 57-12.02	Indicator of cooking and canning behavior and the number of seeds that may not rehydrate.
11. Swelling Capacity (%)	Determined by measuring the volume before hydration (i.e., soaking) and after. The percentage increase was then determined.	Indicator of the amount of volume regained by a pulse after being re-hydrated.
12. Color	Konica Minolta CR-410 Chroma meter. The L*, a* and b* values were recorded.	Indicator of visual quality and the effect of processing on color.
13. Color Difference (ΔE^*ab)	The color difference between the dried (pre-soaked) and the soaked pulse was determined using L*, a* and b* values from the color analysis as follows (*Minolta*): $\Delta E^*ab = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$	Indicator of general color difference between pre- and post-soaked pulses. The lower the value, the more stable is the color.
14. Starch Properties (RVU)	Rapid Visco Analyzer following a modified AACC Approved Method 61-02.01. Modification included a different heating profile and longer running time. Gel firmness was completed 2 hours after the RVA. Sample was compressed at a speed of 4 mm/s to a distance of 15 mm and trigger force of 2 g with a cylindrical plunger (diameter=10 mm)	Indicator of texture, firmness, and gelatinization properties of the starch.
15. Cook Firmness	AACC Approved Method of Analysis, Method 57-14.01	Indicator of pulse firmness after a cooking process. The information allows for a relative difference in texture to be established.
16. Emulsion Properties	Maskus, et al. (2016). Cereal Foods World. 61(2): 59-64.	Indicator of the ability of the flour to facilitate the formation of an emulsion from oil and water when subjected to shear.
17. Foaming Properties	Stone, et al. (2015). Food Research International 76:31-38.	Indicator of the ability of the flour to foam when flour or protein is made into a solution and subjected to shear.
18. Water Holding Capacity	AACC Approved Method of Analysis, Method 57-13.01.	Indicator of the weight of water that will bind to one gram flour. Important parameter for producing meat and bakery products.
19. Oil Holding Capacity	Method of Wang et al. (2020). Cereal Chemistry 97:1111-1117.	Indicator of the weight of oil that will bind to one gram flour. Important parameter for producing meat and salad dressing products.
20. Canning Quality	Followed methods associated with quality attributes 9, 11, 13 and 15. Canning was completed in laminated metal cans using calcium chloride brine and processing 20 minutes and 20 psi for pea and 70 minutes at 20 psi for chickpea.	Indicator of pulse quality after a canning process and 3-week storage. The information allows for a relative difference in quality to be established following a canning process that used a brine solution containing calcium chloride.

Dry Pea Quality Results

Sample distribution

A total of 48 dry pea samples were collected from Montana, North Dakota, and Washington from August 2023 to November 2023. Samples were delivered to SDSU between October 2023 and February 2024. Growing location, number of samples, market class, and genotype details of these dry pea samples are provided in Table 3. The majority of the pea samples were obtained from Montana and Washington. Green peas accounted for 22 of the samples collected, where Hampton accounted for 4 of the green pea samples and Passion and Ginny 2 accounted for three samples each.

Yellow peas accounted for 19 of the pea samples collected. The samples collected were a mix of cultivars listed in Table 3 but CDC Meadow and Salamanca each accounted for three samples each. Winter (7) peas were evaluated in 2023. The Blaze and Vail cultivars accounted for most of the samples evaluated.

Table 3. Description of dry pea samples used in the 2023 pulse quality survey.

State	No. of Samples	Market Class	Cultivars	
Idaho	4	Green	Banner	Passion
		Winter	Vail (Green)	
Montana	32	Green	Aragon	Arcadia
			CDC Forest	Ginny 2
			Hampton	Striker
		Yellow	CDC Leroy	CDC Meadow
			Hyline	Montech
			Orchestra	Salamanca
			Spider	Thunderbird
			Treasure	
Oregon	1	Green	Ariel	
South Dakota	1	Yellow	PUNS0667	
Washington	10	Green	Banner	Compass
			Passion	
		Winter	Blaze (Yellow)	Keystone (Green)
			Goldenwood (Yellow)	

Proximate composition of dry pea

(Tables 4-6)

Moisture

The moisture content of dry pea ranged from 6.9-11.7% in 2023 (Table 4). The mean moisture content of all pea samples was 9.4%, which is lower than the 5-year mean of 10.1% and the 10-year mean (9.8%). The moisture content is lower than the 14% recommended for general storability; however, long term storage under dry conditions could reduce seed moisture to lower levels where damage during storage and handling could occur. In 2023, no samples had a moisture content greater than 13%. Most pea samples had moisture contents between 8.8% and 10%. The mean moisture contents between the three market/color classes were nearly identical. Mean moisture contents ranged from 8.6 % in winter peas to 9.6% for the green peas (Table 5). The green seed moisture percentage of 9.6 was comparable to both the 5- and 10-year mean moisture contents of 9.7 and 9.4%, respectively. The yellow pea mean moisture percentage was 9.5, which was over one percentage point lower than the 5- and 10-year mean values (Table 5). Overall, the mean moisture contents of the green and yellow peas from 2023 were most like moisture contents in peas from 2022. Winter peas had lower moisture percentages in 2023 compared to winter peas from 2022 but similar to the values in 2021. The highest moisture contents were observed in the Ginny 2 (i.e., green pea) and Puns 0667 (yellow pea) cultivars (Table 6). Except for five samples, all other peas had values less than 10%. Keystone was the only winter pea that had a moisture content above 9%.

Table 4. Proximate composition of dry pea grown in the USA, 2019-2023.

Proximate Composition (%)*	Year							
	2023		2022	2021	2020	2019	5-year	10-year
	Range	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Moisture	6.9-11.7	9.4 (1.2)	9.3 (1.1)	9.7 (1.3)	9.5 (1.3)	12.4 (1.7)	10.1 (1.3)	9.8 (1.6)
Ash	2.0-3.0	2.3 (0.3)	2.8 (0.1)	2.6 (0.2)	2.5 (0.5)	2.4 (0.2)	2.6 (0.1)	2.5 (0.1)
Fat	0.4-1.6	1.0 (0.2)	1.2 (0.2)	1.0 (0.2)	1.7 (0.6)	2.0 (0.4)	1.8 (0.7)	**
Protein	19.5-28.8	22.9 (2.2)	23.4 (1.5)	23.1 (1.1)	21.4 (1.5)	21.0 (1.4)	22.0 (1.1)	22.4 (1.6)
Total Starch	35.7-45.2	40.9 (2.0)	42.6 (3.2)	42.9 (1.9)	44.4 (3.1)	43.2 (1.5)	43.2 (0.7)	44.6 (3.7)

*composition is on an "as is" basis. **test not completed for 10 years.

Table 5. Proximate composition of different market classes of dry pea grown in the USA, 2019-2023.

Proximate Composition (%)*	Mean (SD) of green pea 2023	2022	2021	2020	2019	5-year Mean (SD)	10-year Mean (SD)
Moisture	9.6 (1.3)	9.4 (1.5)	9.4 (0.9)	9.2 (1.3)	11.5 (1.8)	9.7 (1.0)	9.4 (1.7)
Ash	2.4 (0.2)	2.8 (0.2)	2.6 (0.2)	2.6 (0.3)	2.4 (1.8)	2.6 (0.1)	2.5 (0.1)
Fat	1.0 (0.2)	1.2 (0.2)	1.0 (0.2)	1.6 (0.6)	2.1 (0.3)	1.8 (0.8)	nd
Protein	23.9 (2.3)	23.2 (2.1)	23.3 (1.0)	23.5 (1.3)	21.3 (0.2)	22.7 (1.0)	22.3 (1.0)
Total Starch	39.9 (2.0)	43.1 (2.2)	42.7 (1.4)	45.1 (3.0)	43.1 (1.5)	43.3 (1.1)	43.7 (3.2)
Proximate Composition (%)*	**Mean (SD) of yellow pea 2023**	**2022**	**2021**	**2020**	**2019**	**5-year Mean (SD)**	**10-year Mean (SD)**
Moisture	9.5 (1.0)	9.3 (1.4)	10.8 (0.6)	9.9 (1.1)	12.9 (1.4)	10.6 (1.4)	10.3 (1.6)
Ash	2.3 (0.1)	2.8 (0.1)	2.5 (0.1)	2.4 (0.6)	2.4 (1.2)	2.5 (0.2)	2.5 (0.1)
Fat	1.1 (0.2)	1.2 (0.1)	1.1 (0.1)	1.7 (0.6)	1.9 (0.4)	1.7 (0.6)	nd
Protein	21.7 (1.4)	22.6 (0.9)	23.0 (1.0)	21.4 (1.3)	20.8 (0.2)	21.8 (1.0)	21.6 (1.0)
Total Starch	41.8 (1.7)	45.6 (1.1)	43.5 (2.5)	43.9 (3.0)	43.4 (1.5)	43.8 (1.1)	44.1 (3.0)
Proximate Composition (%)*	**Mean (SD) of winter pea 2023**	**2022**	**2021**	**2020**	**2019**	**5-year Mean (SD)**	**10-year Mean (SD)**
Moisture	8.6 (0.4)	9.2 (0.5)	8.4 (0.9)	7.8 (0.9)	9.5 (0.2)	9.3 (0.6)	nd
Ash	2.8 (0.2)	2.9 (0.1)	2.7 (0.2)	2.5 (0.1)	2.5 (1.2)	2.6 (0.2)	nd
Fat	1.0 (0.2)	1.1 (0.1)	0.8 (0.1)	1.7 (0.4)	1.9 (0.1)	1.5 (0.5)	nd
Protein	23.4 (2.6)	24.1 (1.2)	23.1 (1.5)	21.3 (1.3)	21.3 (0)	22.2 (1.3)	nd
Total Starch	41.9 (1.8)	40.0 (2.8)	43.5 (1.3)	46.1 (2.4)	42.5 (1.2)	42.5 (1.5)	nd

*composition is on an "as is" basis. nd = not determined due to test not being performed for 10 years on samples.

Ash

The ash content of dry pea ranged from 2.0 to 3.0%, with a mean of 2.3%. The mean ash content (2.3%) of dry peas grown in 2023 was lower than the 5- and 10-year mean ash contents of 2.6 and 2.5%, respectively (Table 4). Ash content is a general indicator of minerals present and has been consistent over the ten-year evaluation of peas. The ash contents of green and yellow peas were 2.4 and 2.3%, respectively (Table 5). The green and yellow pea ash contents were slightly lower than their respective 5- and 10- year mean ash values of approximately 2.5%. Winter peas had a 2.8% ash content, which was slightly higher than the 5-year mean ash content of 2.6 (Table 5). The ash percentage in individual samples ranged from 2.1% in Striker to 2.7% in Compass green peas (Table 6). For yellow peas, CDC Leroy (2.1%) and Hyline (2.5%) had the lowest and highest ash contents, respectively. Keystone and Goldenwood had the highest (3.0%) ash content among winter peas while Blaze had the lowest ash content (Table 6).

Table 6. Mean proximate composition of dry pea cultivars grown in the USA in 2023.

Market Class	Cultivar	Concentration (%) Moisture	Ash	Fat	Protein	Starch
Green	Aragon**	9.9	2.4	1.2	24.9	38.5
	Arcadia	10.4	2.2	1.1	22.9	39.8
	Ariel**	9.4	2.5	1.0	21.5	36.8
	Banner	7.4	2.6	0.9	25.4	41.5
	CDC Forest**	10.3	2.3	1.0	22.0	40.4
	Compass	8.6	2.7	0.5	26.7	38.1
	Ginny 2	10.7	2.2	1.1	22.6	40.4
	Hampton	9.3	2.4	1.1	23.7	39.7
	Passion	9.5	2.6	1.1	23.7	42.6
	Striker	10.5	2.1	0.9	24.6	38.2
Yellow	CDC Leroy**	9.8	2.1	1.1	21.2	41.9
	CDC Meadow	8.6	2.3	1.2	23.3	41.5
	Hyline**	9.3	2.5	0.9	21.3	42.9
	Montech**	10.3	2.3	1.1	20.8	42.4
	Orchestra**	9.5	2.3	0.9	22.9	41.1
	Puns 0667**	11.3	2.4	1.3	20.4	38.7
	Salamanca	10.3	2.4	1.0	21.5	41.6
	Spider**	9.5	2.4	1.3	20.9	40.9
	Thunderbird**	8.7	2.2	0.7	21.3	43.3
	Treasure**	7.7	2.3	1.0	19.5	45.2
	Unknown	9.4	2.1	1.2	22.0	41.7
Winter Green	Keystone**	9.1	3.0	1.1	25.5	40.6
	Vail	8.6	2.8	1.1	24.2	41.0
Winter Yellow	Blaze	8.5	2.6	1.0	21.7	43.4
	Goldenwood**	8.2	3.0	0.5	24.7	40.9

**Only one sample of cultivar tested

Fat (Lipid)

The fat content of dry pea ranged from 0.4 to 1.6%, with a mean of 1.0% (Table 4). The mean fat content (1.0%) of pea harvested in 2023 was lower than fat content of pea harvested in previous years except from 2021. In addition, the fat content (1.0%) was lower than the 5-year mean fat content (1.8%). The fat contents of the green and yellow market classes were the same as the fat contents in winter peas (Table 5). Overall, the mean fat content in the green and yellow peas were lower than the 5-year mean values (1.8 and 1.7%, respectively). The mean fat content (1%) of winter peas also was lower than the 5-year mean value (1.5%). The Aragon cultivar had the highest fat content (1.5%) among green pea cultivars while PUN 0667 and Spider had the highest fat contents of the yellow peas (Table 6). Regardless of color, most other cultivars had fat contents around 1.0-1.1% (Table 6). For the winter pea samples, Goldenwood had the lowest (0.5%) fat content while the other winter peas had fat content of approximately 1.1%.

Protein

Protein content of dry pea harvested in 2023 ranged from 19.5 to 28.8% with a mean of 22.9% (Table 4). The mean protein content of peas from 2023 was comparable to the value for peas from 2021. Furthermore, the mean protein (22.9%) was higher than the 5- and 10-year mean protein contents of 22.0 and 22.4%, respectively (Table 4). The mean protein contents of the green, yellow, and winter pea samples were 23.9, 21.7, and 23.4%, respectively (Table 5). Green pea samples had a mean protein content that was higher than the 5- and 10-year mean values of 22.7 and 22.3%, respectively. Yellow peas had a mean protein content that was comparable to the 5- and 10-year mean protein contents of 21.8 and 21.6%, respectively (Table 5). The protein content of Winter peas was 23.4%, which was higher than the 5-year mean value of 22.2%. The data supports higher protein content in recent years compared to long-term mean values. The Compass cultivar had the highest mean protein content (26.7%) while Ariel had the lowest (21.5%) among green peas (Table 6). CDC Meadow and Treasure cultivars had the highest (23.3%) and lowest (19.5%) protein contents of the yellow market class, respectively (Table 6). In winter peas, Keystone and Blaze had the highest (25.5%) and lowest (21.7%) protein contents, respectively.

Total starch

Total starch content of dry pea ranged from 35.7 to 45.2% with a mean of 40.9% (Table 4). The mean total starch content of dry peas grown in 2023 was lower to mean total starch in dry peas from the 2022 and 2019 harvest years and was lower than both the 5- and 10-year mean total starch values of 43.2 and 44.6%, respectively. The starch contents of the green and yellow market classes were 39.9 and 41.8%, respectively (Table 5). Green peas had a mean starch content (39.9%) that was significantly lower than the 5-year and 10-year mean values of 43.3% and 43.7%, respectively. The 5- and 10-year mean starch contents for the yellow peas were 43.8 and 44.1%, respectively. These values were higher than the mean starch content (41.8%) of yellow peas harvested in 2023. Winter peas from 2023 had a mean starch content (41.9%) that was lower than winter peas from previous harvest years except 2022 (Table 5). Furthermore, the mean starch value of winter peas from 2023 was lower than the 5-year mean value of 42.5%.

Among green peas, Compass and Passion had the highest (38.1%) and lowest (42.6%) total starch contents, respectively. PUN 0667 and Treasure had the lowest (38.7%) and highest (45.2%) total starch contents among yellow peas. Keystone and Blaze had the lowest (40.6%) and highest (43.4%) total starch contents among winter pea samples (Table 6). The Blaze cultivar also had the highest (49.6%) total starch in 2021 and suggests that production year may impact the starch content (Table 6).

The general trend for all samples supports higher protein and lower starch and fat contents in samples grown in 2023 compared to previous years. Unlike previous years, widespread drought conditions were not experienced in 2023 like that in the summer of 2021 and thus lower starch contents may have been impacted more by varieties evaluated than environmental conditions.

Physical parameters of dry pea (Tables 7-11)

Test weight ranged from approximately 61 to 67 lbs./Bu with a mean of 64 lbs./Bu. This mean value was approximately the same as the 5- and 10-year mean values of 63.2 and 63.3 lbs./Bu (Table 7). The mean test weight for all pea samples harvested in 2023 was comparable to those harvested in 2020. The test weights of peas in the green and yellow market classes were 63.1 and 64.6 lbs./Bu, respectively (Table 8). The mean value for green pea was comparable to the 5- and 10-year mean test weights. In contrast, the mean test weight for the yellow peas in 2023 was higher than both the 5- and 10-year year mean values. Winter peas had a mean test weight at 63.2 lbs./Bu, which was lower than the winter peas from previous harvest years. The test weight of individual cultivars varied within their respective green and yellow market classes with few exceptions (Table 9). Aragon and Ginny 2 (green) and CDC Leroy (yellow) had the highest test weights in their respective market classes. The lowest test weights were 61.5 and 62.3 lbs./Bu for the Compass (green) and PUNS0667 (yellow) varieties, respectively (Table 9). Among the winter peas, the Blaze cultivar had the highest test weight while the Goldenwood cultivar had the lowest test weight (Table 9).

Table 7. Physical parameters of dry pea grown in the USA, 2019-2023.

Physical Parameter	Year							
	2023		2022	2021	2020	2019	5-year	10-year
	Range	Mean (SD)		Mean	Mean	Mean	Mean (SD)	Mean (SD)
Test Weight (lb/bu)	61.3-66.7	63.7 (1.2)	59.5 (5.9)	64.7 (1.3)	63.6 (1.9)	64.3 (1)	63.2 (2.1)	63.3 (1.5)
1000 Seed Wt (g)	130-283	194 (34)	182 (41)	199 (40)	233 (33.0)	224 (31)	210 (20)	213 (15)
Water Hydration Capacity (%)	82-147	102 (9)	112 (6)	100 (6)	97 (8.0)	96 (8)	102 (6)	102 (6)
Unhydrated Seeds (%)	0-15	2 (3)	1 (4)	0 (1)	2 (3)	2 (3)	1 (1)	2 (2)
Swelling Capacity (%)	104-181	133 (14)	141 (19	146 (12)	118 (12.4)	145 (13)	139 (12)	nd
Cooked Firmness (N/g)	7.9-32.0	22.6 (6.2)	22.1 (7.3)	24.0 (5.2)	24.9 (6.3)	21.0 (7)	22.6 (1.8)	nd

nd = not determined due to test not being performed for 10 years.

Table 8. Physical parameters of different market classes of dry pea grown in the USA, 2019-2023.

Physical Parameter	Mean (SD) of green pea					5-year	10-year
	2023	2022	2021	2020	2019	Mean (SD)	Mean (SD)
Test Weight (lb/bu)	63.1 (1.0)	59.3 (5.9)	64.4 (1.9)	64 (2)	64 (1)	62.7 (2.0)	62.9 (1.4)
1000 Seed Wt (g)	193 (29)	182 (45)	193 (26)	220 (31)	207 (28)	196 (14)	202 (14)
Water Hydration Capacity (%)	102 (12)	111 (8)	105 (3)	99 (7)	99 (6)	105 (4)	105 (5)
Unhydrated Seeds (%)	3 (4)	3 (6)	0 (0)	2 (2)	1 (1)	1 (1)	2 (2)
Swelling Capacity (%)	133 (12)	137 (31)	149 (12)	120 (12)	144 (10)	141 (13)	nd
Cooked Firmness (N/g)	23.0 (4.5)	24.2 (5.8)	21.4 (5.5)	21.7 (4)	18.9 (4.6)	21.5 (1.7)	nd
Physical Parameter	**Mean (SD) of yellow pea**					**5-year**	**10-year**
	2023	**2022**	**2021**	**2020**	**2019**	**Mean (SD)**	**Mean (SD)**
Test Weight (lb/bu)	64.6 (1.1)	54.2 (5.9)	63 (2)	64 (1)	63 (1)	62.0 (4.4)	62.6 (3.0)
1000 Seed Wt (g)	207 (36)	221 (30)	244 (28)	222 (31)	214 (30)	229 (10)	226 (10)
Water Hydration Capacity (%)	98 (5)	108 (5)	93 (7)	102 (8)	102 (5)	100 (6)	100 (6)
Unhydrated Seeds (%)	3 (2)	0 (0)	2 (3)	0 (2)	1 (1)	1 (1)	2 (2)
Swelling Capacity (%)	131 (14)	143 (20)	116 (12)	146 (14)	150 (9)	138 (13)	nd
Cooked Firmness (N/g)	24.5 (6.5)	28.3 (7.1)	27.2 (6.6)	22.0 (7.1)	21.7 (5)	25.1 (2.9)	nd
Physical Parameter	**Mean (SD) of winter pea**					**5-year**	**10-year**
	2023	**2022**	**2021**	**2020**	**2019**	**Mean (SD)**	**Mean (SD)**
Test Weight (lb/bu)	63.2 (1.1)	63.6 (0.9)	65.0 (0.7)	65 (0.4)	65 (0)	nd	nd
1000 Seed Wt (g)	161 (24)	152 (12)	156 (14)	175 (12)	154 (39)	nd	nd
Water Hydration Capacity (%)	110 (3)	115 (2)	103 (5)	96 (5)	85 (8)	nd	nd
Unhydrated Seeds (%)	0 (1)	1 (1)	0 (0)	1 (1)	7 (8)	nd	nd
Swelling Capacity (%)	141 (24)	141 (6)	156 (7)	119 (8)	131 (3)	nd	nd
Cooked Firmness (N/g)	16.1 (6.7)	16.0 (2.1)	24.3 (3.7)	21.6 (1.6)	24.6 (8.3)	nd	nd

nd = not determined due to test not being performed for 5 or 10 years.

Table 9. Mean physical parameters of USA dry pea cultivars grown in 2023.

Market Class	Cultivar	Test Weight (lb/bu)	1000 Seed Weight (g)	Water Hydration Capacity (%)	Unhydrated Seeds (%)	Swelling Capacity (%)	Cooked Firmness (N/g)
Green	Aragon**	64.0	175	101	2	125	22.6
	Arcadia	63.2	225	120	1	128	28.8
	Ariel**	62.4	184	101	0	150	19.0
	Banner	62.6	202	103	1	135	27.7
	CDC Forest**	62.0	243	96	1	132	21.0
	Compass	61.5	142	107	2	128	20.8
	Ginny 2	64.0	214	97	5	131	26.3
	Hampton	63.4	175	105	1	135	19.1
	Passion	63.1	186	103	0	147	22.6
	Striker	63.4	207	91	9	123	22.5
Yellow	CDC Leroy**	66.7	145	91	7	119	29.8
	CDC Meadow	64.6	187	106	2	135	23.8
	Hyline**	63.6	248	96	1	129	29.1
	Montech**	62.4	231	97	2	119	28.7
	Orchestra**	65.0	247	101	2	135	23.2
	Puns 0667**	62.3	247	90	3	118	27.0
	Salamanca	64.1	211	102	1	132	25.3
	Spider**	65.3	185	98	9	133	25.6
	Thunderbird**	63.6	202	95	0	111	31.2
	Treasure**	65.7	221	100	0	130	20.1
	Unknown	64.9	202	98	3	137	21.7
Winter Green	Keystone**	62.7	130	113	0	181	7.9
	Vail	63.0	149	112	0	118	12.8
Winter Yellow	Blaze	64.0	185	107	0	148	18.7
	Goldenwood**	61.6	144	109	2	127	23.2

**Only one sample of cultivar tested

The range and mean **1000 seed weight** of dry peas grown in 2023 were 130-282 g and 194 g, respectively (Table 7). The mean value (182 g) was lower than the 5- and 10-year mean 1000 seed weight of peas. This supports lighter seeds for the peas harvested in 2023 compared to long term averages. Peas of the green market class had a mean 1000 seed weight of 193 g, which is lower than the 5- and 10-year mean value 1000 seed weights of 196 and 202 g, respectively (Table 8). Green peas had the same 1000 seed weight as green peas grown in 2021. Peas of the yellow market class had a mean 1000 seed weight of 207 g, which is lower than the 5- and 10-year mean 1000 seed weight (Table 8). Winter pea samples harvested in 2023 had higher 1000 seed weight compared to peas harvested in previous years except 2020.

The individual cultivars (Table 9) varied extensively in 1000 seed weight, where the Compass and CDC Forest cultivars in the green market had the lowest (142 g) and highest (243 g) 1000 seed weight. CDC Leroy (145 g) and Hyline (248 g) had the lowest and highest 1000 seed weight in the yellow market class, respectively (Table 9). The Keystone and Blaze winter peas had lowest (130 g) and highest (185 g) 1000 seed weight, respectively.

The water absorption or hydration properties of peas are important for understanding how peas will hydrate and increase in size and weight. We can measure hydration properties by measuring water hydration capacity, percentage of unhydrated seeds and swelling capacity.

Water hydration capacity of dry peas ranged from 82 to 147%, with a mean of 102% (Table 7). In 2023, mean water hydration capacity was lower than value from 2022 but was the same as the 5- and 10-year mean water hydration capacity of 102 and 102%, respectively. The mean water hydration capacity of peas in the green market class was 4 percentage points higher than the mean hydration capacity of the yellow market class but was 8 percentage points lower than the water hydration capacity of the winter peas (Table 8). The mean water hydration capacity of the green peas in 2023 was slightly lower than the 5- and 10-year mean water hydration capacities (Table 8). The yellow peas from 2023 had a mean water hydration capacity that was slightly lower than the 5- and 10-year mean water hydration capacities. In the green market class, Striker and Arcadia had the lowest (91%) and highest (120%) water hydration capacities, respectively. The water hydration capacity ranged from 90% in Puns 0667 to 106% in the CDC Meadow cultivar of yellow peas (Table 9). The Blaze and Keystone cultivars had the lowest (107%) and highest (113%) water hydration capacity in the winter peas. The water hydration capacity for winter peas was lower than the values in 2022 that ranged from 112 to 120%.

Unhydrated seed percentage ranged from 0-15% with a mean of 2%, which is comparable to the 5- and 10-year mean unhydrated seed percentage (Table 7). Green and yellow peas had unhydrated seed values of 3% (Table 8). Winter peas had 0% unhydrated seed rate. The yellow pea samples had higher unhydrated seed percentages than the 5- and 10-year mean values (Table 8). Most of the green pea cultivars had unhydrated seed rates of 0-2%; however, a 9% unhydrated seed rate was found in the Striker cultivar and thus contributed to the higher mean unhydrated percentage (Table 9). The yellow cultivars had 0-3% unhydrated seed counts except for CDC Leroy and Spider. The Goldenwood cultivar in the winter peas was the only cultivar that had an unhydrated seed percentage greater than 0 and suggest that no issues should occur during rehydration of the peas.

The **swelling capacity** is the amount of swelling that occurred during re-hydration of the dry pea. The swelling capacity of all peas ranged from 104% to 181% with a mean value of 133% (Table 7). The mean swelling capacity for peas from the 2023 harvest was comparable to the 5-year mean swelling capacity (Table 7). The mean swelling capacity was higher than the value reported for the 2020 samples but lower than samples from previous harvest years. The swelling capacity of green peas from 2023 was the same as mean swelling capacity of the yellow peas (Table 8). However, the green and yellow peas had lower swelling capacities than winter peas.

The green and yellow peas had swelling capacities that were lower than their respective 5-year mean swelling capacities. Variability in the swelling capacity among cultivars was observed (Table 9). Striker (green) and Thunderbird (yellow) had the least swelling capacity among commercial cultivars. Ariel (green) and CDC Meadow and Orchestra (yellow) had the highest swelling capacities among the cultivars evaluated (Table 9). The swelling capacity among winter peas ranged from 118% (Vail) and 181% (Keystone).

The **cooked firmness** values for all peas combined were the same in the peas from 2023 compared to the 5-year mean cooked firmness. The cooked firmness for all peas ranged from 7.9 to 32.0 N/g with a mean value of 22.6 N/g (Table 7). The cooked firmness of peas was different between market classes (Table 8). The winter peas had lower firmness values than those of the green and yellow peas. In contrast to the overall cooked firmness, the mean cooked firmness of green and yellow peas obtained in 2023 were higher and lower than the 5-year mean value, respectively (Table 8). The winter peas had mean cooked firmness well below the firmness of cooked winter peas from previous years except 2022. Among the green cultivars, Ariel had the lowest cooking firmness (19.0 N/g) while Arcadia (28.8 N/g) was the firmest among commercial cultivars (Table 9). Treasure and Thunderbird had the lowest (20.1 N/g) and highest (31.2 N/g) cooked firmness, respectively (Table 9). The winter peas had cooked firmness values that ranged from 7.9 to 23.2 N/g.

Color quality was measured using an L*, a*, and b* and from these values a color difference can be determined on peas before and after soaking. **Color quality** for the pea samples in 2023 indicated that the green peas had L* values that were higher than the 5- and 10-year mean L* values (Table 10). The L* values for green peas in 2023 matched the L* for peas from 2022 and 2020. Overall, the high L* indicates that the green peas from the 2023 crop year were lighter in color than those from the 2021 harvest year. The negative value for red-green (i.e., a* value) value in 2023 indicates slightly less green color compared to samples from 2020-2022 (Table 10). The a* value for green peas from 2023 was comparable to the 5-year mean a* values indicating that the peas had similar greenness. However, the samples were less green compared to the 10-year mean a* value. The b* value was most comparable to the green peas from 2020 but was significantly lower than the 5- and 10- year mean b* values. The lower b* value indicates a bluer color. The lower (more negative) a* combined with a lower b* value indicates that the peas would be a light blue green color. Therefore, the green peas in 2023 appear slightly lighter green in color compared to peas with a long term.

The mean L* value of yellow peas was substantially higher than the 5-year mean L* but only slightly higher than the 10-year L* value (Table 10). indicating that the peas in 2023 were slightly lighter than samples from peas that made up the 5-year mean L* but had comparable lightness to samples that made up the long-term (10 year). For the yellow pea

Table 10. Color quality of dry pea grown in the USA before and after soaking in water 16 hours, 2020-2023 and 5- and 10-year mean values.

Color Scale*	Mean (SD) of Green Pea											
	Before Soaking						After Soaking					
	2023	2022	2021	2020	5-Year	10-Year	2023	2022	2021	2020	5-Year	10-Year
L (lightness)	58.27 (2.11)	58.45 (2.23)	57.34 (2.63)	58.82 (2.75)	55.06 (3.98)	57.03 (5.25)	52.93 (3.72)	52.55 (2.15)	53.41 (2.63)	54.69 (3.26)	51.31 (3.23)	52.29 (4.39)
a (red-green)	-1.25 (1.73)	-1.97 (0.56)	-2.21 (1.25)	-1.35 (1.97)	-1.98 (0.37)	-1.74 (1.55)	-6.65 (3.11)	-7.40 (0.59)	-7.43 (1.67)	-6.47 (3.45)	-6.75 (0.55)	-7.61 (2.72)
b (yellow-blue)	9.63 (1.64)	10.16 (0.68)	10.14 (1.28)	9.84 (1.51)	10.70 (1.76)	12.07 (2.50)	18.01 (3.44)	17.73 (1.98)	16.11 (2.57)	17.50 (3.24)	18.50 (5.33)	22.38 (6.56)
Color Difference	11.78 (1.59)	11.10 (1.98)	9.04 (2.18)	10.78 (1.93)	10.76 (3.29)	nd						
Color Scale	Mean (SD) of Yellow Pea											
	Before Soaking						After Soaking					
	2023	2022	2021	2020	5-Year	10-Year	2023	2022	2021	2020	5-Year	10-Year
L (lightness)	63.45 (1.35)	63.57 (1.34)	63.30 (1.01)	63.42 (2.64)	61.15 (2.87)	62.99 (5.01)	62.73 (1.44)	62.54 (1.13)	63.91 (0.64)	65.03 (1.47)	62.44 (1.89)	65.20 (4.93)
a (red-green)	4.97 (0.50)	4.80 (0.95)	4.29 (1.16)	4.99 (0.68)	5.19 (0.89)	5.81 (1.10)	5.16 (0.61)	4.74 (0.65)	5.16 (1.16)	5.50 (0.75)	5.13 (0.82)	6.04 (1.93)
b (yellow-blue)	15.34 (0.59)	15.53 (0.33)	11.73 (2.32)	14.61 (0.95)	15.11 (2.41)	17.18 (3.42)	31.04 (2.71)	29.76 (0.62)	22.06 (2.57)	28.89 (1.41)	27.91 (5.99)	31.55 (7.73)
Color Difference	16.31 (0.99)	14.29 (0.50)	13.53 (2.18)	14.63 (2.06)	14.00 (3.39)	nd						

*color scale: L (lightness) axis – 0 is black and 100 is white; a (red-green) axis – positive values are red, negative values are green, and zero is neutral; and b (yellow-blue) axis – positive values are yellow, negative values are blue, and zero is neutral. **Only one sample of cultivar tested

Table 11. Color quality of USA dry pea cultivars before and after soaking, 2023.

Market Class	Cultivar	Before Soaking L	Before Soaking a	Before Soaking b	After Soaking L	After Soaking a	After Soaking b	Color Difference
Green	Aragon**	57.51	-2.40	9.67	50.91	-8.52	18.25	12.49
	Arcadia	60.19	-0.70	10.04	54.12	-6.62	17.77	11.49
	Ariel**	58.58	-2.13	8.94	50.30	-8.09	16.09	12.47
	Banner	54.34	-1.95	8.92	49.52	-7.60	16.13	10.41
	CDC Forest**	63.23	5.30	15.84	65.36	4.97	32.40	16.81
	Compass	55.52	-1.71	7.91	49.68	-6.97	15.76	11.28
	Ginny 2	58.85	-1.78	9.25	53.11	-7.53	17.54	11.78
	Hampton	58.49	-2.05	9.65	52.55	-8.24	17.27	11.68
	Passion	58.09	-1.88	9.35	50.98	-8.24	17.26	12.42
	Striker	59.28	-0.11	9.74	56.29	-4.02	18.86	10.55
Yellow	CDC Leroy**	63.17	4.99	15.64	63.68	5.08	31.69	16.06
	CDC Meadow	62.72	4.36	15.59	64.32	4.73	32.67	17.46
	Hyline**	64.88	5.21	15.33	63.05	4.94	30.82	15.61
	Montech**	65.31	5.45	16.14	59.21	5.76	20.69	14.53
	Orchestra**	65.16	4.95	14.70	64.12	4.26	31.17	16.52
	Puns 0667**	59.96	4.92	14.14	60.94	5.56	29.30	15.21
	Salamanca	64.16	4.97	14.89	62.96	5.14	31.23	16.42
	Spider**	62.43	4.79	15.17	62.27	4.94	30.78	15.62
	Thunderbird**	62.05	4.31	15.63	62.20	5.14	31.68	16.08
	Treasure**	65.03	4.90	15.67	64.48	4.18	32.04	16.40
	Unknown	63.39	5.18	15.45	62.48	5.49	31.98	16.59
Winter Green	Keystone**	56.76	0.19	9.06	54.25	-5.74	17.63	10.76
	Vail	51.80	-1.30	8.12	47.57	-6.74	16.11	10.62
Winter Yellow	Blaze	59.73	3.21	15.01	60.20	3.67	30.11	15.12
	Goldenwood**	59.87	4.56	12.89	60.83	4.69	27.55	14.70

Mean Color Values*

*color scale: L (lightness) axis – 0 is black and 100 is white; a (red-green) axis – positive values are red, negative values are green, and zero is neutral; and b (yellow-blue) axis – positive values are yellow, negative values are blue, and zero is neutral. **Only one sample of cultivar tested.

market class, the L* mean value of peas matched the L* values of yellow peas from 2020-2022. The a* value of the yellow peas was on the red side of the scale indicating the lack of a green appearance. The yellow pea in 2023 had a* values that were like the a* values in peas from 2020. However, the a* values for yellow peas from 2023 were less than the 5- and 10-year mean a* (Table 10). Similarly, the b* values for peas in 2023 were less than the 10-year mean b* value but higher than the 5-year mean b* value. This indicates that the peas from 2023 were more yellow than the 5-year mean same but less yellow compared to samples that made up the 10-year mean. The b* value for the peas from 2023 was higher than for peas from 2020 and 2021 but like the b* value of peas from 2022. This indicates that the yellowness of peas from 2023 was comparable to peas from 2022 but was greater than that of peas from 2020 and 2021. A higher b* values combined with an a* value on the red part of the scale indicates that the samples would be light yellow in color. A lower a* combined with a lower b* values indicates that the pulses would be a darker yellow to light brown color. Therefore, the yellow peas in 2023 appeared yellow to dark yellow in color compared to peas from 2020 and 2021. The color of the dry peas changed after the soaking process. The change in color as measured by color difference was greater for green peas from 2023 compared to the peas from previous crop years (Table 10). The green peas became darker (lower L*) while the a* value became more negative (i.e., greener), but more yellow (i.e., increased b* value). This trend was like previous crop years. In 2023, lightness decreased slightly after soaking of the yellow peas. The changes (11.78) were slightly more than compared to the 5-year mean (10.76). However, the 5 and 10-year mean L* value indicate darker peas after soaking compared to the samples from 2023 (Table 10). In addition, soaking caused a substantial change in greenness (i.e., similar a* value pre- and post-soak) and yellowness (i.e., higher b* value) of the green peas. This suggests that the peas appeared lighter green after soaking (Table 10), but to a lesser degree compared to peas that made up the 5- and 10-year mean color values. The color difference between dry and soaked yellow peas was greater in peas from 2023 compared to previous years (2020-2022) and the 5- and 10-year mean values. The yellow market class underwent more color change during soaking than did the green peas (Table 10). Although color difference is a general indicator of change, visual observations support an increase in yellowness (increased b*) after the soaking process in the yellow peas. The soaked peas from 2023 had L* values that were comparable to the peas from 2022 and lower than peas from other years, indicating darker color. The yellowness (b*) was more intense for the yellow peas from 2023 compared to peas from other years. However, the yellowness of the yellow peas matched the 10-year mean yellowness.

The Banner cultivar had the lowest L* value (Table 11). Aragon had the most negative a* value and one of the lowest b* values, giving it a green appearance. CDC Forest had the highest L*, a* and b* values, giving it a light green appearance. The L* value decreased in all cultivars upon soaking. The a* values became more negative (i.e., greener) and more yellow (i.e., increased b* value) after soaking. This combination of changes resulted in peas that appeared greener. Of the commercial cultivars, the greatest color difference was observed in the CDC Forest cultivar.

Like 2022, Banner had the least color change during soaking. The cultivars of the yellow peas had L* values between 59.96 and 65.31, with Montech being the lightest (Table 11). Treasure had the lightest color after soaking while Montech became the darkest (i.e., lowest L*). Of the commercial cultivars, Thunderbird had the lowest redness (a*) value while Puns 0667 had the lowest yellowness (b*) scores while the highest scores were observed for the Montech cultivar (Table 11).

After soaking, Treasure and Montech cultivars had the lowest and highest redness values, respectively. CDC Medows had the highest yellowness values while Montech had the lowest after soaking. The greatest color difference was observed in the CDC Medows cultivar. The substantial increase in yellowness during soaking likely contributed to the greatest color difference for CDC Medows. Montech had the least color change during soaking.

In 2023, two cultivars each of green and winter pea were evaluated (Table 11). Overall, the vail winter peas tended to be darker green compared to Keystone. The same color trend was observed after soaking. However, both green winter cultivars had the same color difference. The green cultivars were less susceptible to color change compared to the yellow cultivars. The Blaze cultivar tended to be yellower in color compared to Goldenwood regardless of the sample, i.e. dry or soaked (Table 11). However, color difference values were more pronounced in the Blaze cultivar.

Starch Properties (Tables 12-14)

The peas from 2023 had mean peak viscosity, hot and cold paste viscosities, and setback values that were significantly lower than 5- and 10-year mean values for these same parameters (Table 12). Mean peak time was slightly more than the 5-year mean peak time values but the same as the 10-year mean peak time. This indicates that the samples begin to form a paste at the same time as most samples from the 10-year period. The pasting temperature of the samples ranged from 77.2-83.9 °C, with a mean of 80.0°C. The mean value is nearly 2 °C higher than the 5- and 10-year mean pasting temperatures. However, the data for peas overall was likely impacted by the data obtained from the winter peas since some of the samples had high pasting temperatures. Unlike 2022, the starch characteristics were similar between all three market classes.

Table 12. Starch characteristics of dry peas grown in the USA, 2019-2023 and 5- and 10-year mean values.

Starch Characteristic	2023 Range	2023 Mean (SD)	2022 Mean (SD)	2021 Mean (SD)	2020 Mean (SD)	2019 Mean (SD)	5-Year Mean (SD)	10-Year Mean (SD)
Peak Viscosity (RVU)	89-216	126 (22)	114 (23)	126 (17)	134 (5)	146 (15)	132 (12)	136 (10)
Hot Paste Viscosity (RVU)	87-176	116 (17)	105 (20)	118 (15)	124 (14)	131 (12)	121 (10)	127 (8)
Breakdown (RVU)	1-41	10 (7)	9 (5)	9 (5)	10 (5)	16 (6)	11 (3)	8 (4)
Cold Paste Viscosity (RVU)	113-329	162 (35)	176 (33)	204 (38)	229 (38)	233 (30)	215 (25)	229 (22)
Setback (RVU)	19-153	46 (20)	71 (15)	86 (24)	105 (26)	104 (22)	94 (15)	102 (14)
Peak Time (Minute)	5.07-6.84	5.51 (0.41)	5.94 (0.89)	5.37 (0.31)	5.29 (0.41)	5.11 (0.40)	5.34 (0.36)	5.57 (0.93)
Pasting Temperature (°C)	77.2-83.9	80.0 (1.7)	80.6 (2.8)	79.9 (1.8)	77.7 (1.8)	76.4 (1.3)	78.3 (1.8)	77.8 (1.8)
RVA Starch Gel Firmness (g)	79-445	270 (86)	243 (73)	**	**	**	nd	nd

**not previously reported; nd = not determined due to test not being performed for 5 or 10 years.

The pasting values for the green peas were slightly higher than pasting data for the yellow and winter peas. For example, mean peak viscosity of 131 was recorded for the green peas while values of 122 and 118 RVU were recorded for the yellow and winter peas, respectively (Table 13). For the green and yellow peas, pasting properties followed the same trend where the 5- and 10-year mean viscosity were substantially higher than the values for peas from 2023. Pasting values for the winter pea samples were comparable to winter peas from 2019-2021 (Table 13). The pasting temperature was about 1 to 2 °C higher for green and yellow pea samples in 2023 compared to the 5- and 10-year mean pasting temperatures. Winter peas from 2023 had higher pasting temperatures than peas from other harvest years except 2022. Collectively, the data indicates that the starch is behaving in a similar manner to the starch from peas in prior years. New in 2022 was the RVA gel firmness measure. The RVA gel firmness was run again in 2023. The gel firmness varied significantly (79-445 g) where winter pea produced a gel that was the least firm while yellow pea samples had the highest mean (304 g) RVA gel firmness (Tables 12 and 13).

Within each class, variability in starch characteristics was observed among cultivars. In the green pea, the Passion cultivar had the highest peak, hot paste, and cold paste viscosities (Table 14). In contrast, the compass cultivar had the lowest peak, hot paste, and final viscosities. Orchestra had the highest peak and hot paste viscosities while Puns 0667 had the highest cold paste viscosity among yellow cultivars. The lowest peak, hot paste, and cold paste viscosities in the yellow market class were observed in the Montech cultivar (Table 14). The Goldenwood winter pea had the lowest peak, hot paste, and cold paste viscosities of the winter peas. In contrast, Blaze had the highest viscosities. However, type C pasting profile was demonstrated by all of the cultivars tested. This curve is represented by a minimally

Table 13. Starch characteristic of different market classes of dry peas grown in the USA, 2019-2023 and 5- and 10-year mean values.

Physical Parameter	Mean (SD) of Green Pea 2023	2022	2021	2020	2019	5-year Mean (SD)	10-year Mean (SD)
Peak Viscosity (RVU)	131 (26)	131 (13)	127 (23)	138 (16)	143 (17)	136 (7)	138 (7)
Hot Paste Viscosity (RVU)	119 (21)	118 (13)	120 (20)	127 (13)	127 (14)	124 (5)	126 (5)
Breakdown (RVU)	11 (9)	13 (4)	6 (5)	11 (3)	16 (6)	11 (4)	12 (5)
Cold Paste Viscosity (RVU)	167 (45)	194 (28)	209 (53)	239 (40)	220 (32)	218 (17)	226 (18)
Setback (RVU)	48 (26)	75 (17)	89 (35)	112 (29)	93 (22)	94 (14)	101 (14)
Peak Time (Minute)	5.45 (0.35)	5.26 (0.21)	5.48 (0.40)	5.29 (0.30)	5.17 (0.35)	5.30 (0.11)	5.65 (0.90)
Pasting Temperature (°C)	80.3 (1.7)	79.4 (2.2)	80.4 (1.6)	78.3 (1.6)	76.8 (1.3)	78.7 (1.4)	77.9 (1.5)
RVA Gel Firmness (g)	266 (87)	249 (89)	**	**	**	nd	nd
Starch Characteristics	**Mean (SD) of Yellow Pea 2023**	**2022**	**2021**	**2020**	**2019**	**5-year Mean (SD)**	**10-year Mean (SD)**
Peak Viscosity (RVU)	122 (14)	127 (16)	130 (13)	132 (15)	148 (14)	135 (9)	138 (7)
Hot Paste Viscosity (RVU)	113 (13)	117 (13)	120 (12)	122 (13)	133 (10)	125 (7)	126 (6)
Breakdown (RVU)	9 44)	11 (6)	9 (4)	13 (5)	16 (6)	12 (3)	12 (3)
Cold Paste Viscosity (RVU)	157 (24)	196 (28)	205 (30)	223 (34)	240 (27)	220 (20)	226 (18)
Setback (RVU)	43 (14)	79 (15)	84 (19)	101 (23)	110 (20)	96 (14)	100 (13)
Peak Time (Minute)	5.39 (0.24)	5.22 (0.23)	5.37 (0.14)	5.29 (0.48)	5.17 (0.35)	5.25 (0.11)	5.52 (092)
Pasting Temperature (°C)	78.9 (1.15)	78.1 (1.6)	79.9 (0.7)	77.2 (1.7)	76.2 (1.3)	77.7 (1.4)	77.2 (1.4)
RVA Gel Firmness (g)	304 (74)	290 (71)	**	**	**	nd	nd
Physical Parameter	**Mean (SD) of Winter Pea 2023**	**2022**	**2021**	**2020**	**2019**	**5-year Mean (SD)**	**10-year Mean (SD)**
Peak Viscosity (RVU)	118 (21)	91 (13)	121 (14)	126 (11)	134 (19)	nd	nd
Hot Paste Viscosity (RVU)	112 (18)	85 (13)	111 (12)	113 (12)	118 (8)	nd	nd
Breakdown (RVU)	6 (6)	6 (2)	10 (6)	13 (2)	16 (13)	nd	nd
Cold Paste Viscosity (RVU)	157 (30)	147 (19)	197 (28)	216 (33)	209(35)	nd	nd
Setback (RVU)	45 (13)	62 (7)	86 (19)	103 (22)	92 (28)	nd	nd
Peak Time (Minute)	6.04 (0.60)	6.98 (0.05)	5.25 (0.33)	5.18 (0.17)	5.58 (0.91)	nd	nd
Pasting Temperature (°C)	81.8 (1.4)	83.4 (0.7)	80.9 (2.2)	78.8 (1.4)	77.5 (1.5)	nd	nd
RVA Gel Firmness (g)	186 (32)	203 (36)	**	**	**	nd	nd

**not previously reported. nd = not determined due to test not being performed for 5 or 10 years.

definable pasting peak, a small breakdown in viscosity and high final peak viscosity. The breakdown ranged from 1 to 41 RVU, which represents a small amount of breakdown of the starch paste. The setback values ranged from 19 to 153 RVU, which represents a significant setback for some of the samples.

Table 14. Mean starch characteristics of dry pea cultivars grown in the USA in 2023.

Market Class	Cultivar	Peak Viscosity (RVU)	Hot Paste Viscosity (RVU)	Breakdown (RVU)	Cold Paste Viscosity (RVU)	Setback (RVU)	Peak Time (Min)	Pasting Temperature (°C)	Gel Firmness (g)
Green	Aragon**	122	116	7	163	47	5.47	81.5	329
	Arcadia	130	121	9	168	47	5.45	80.8	336
	Ariel**	138	120	18	162	42	5.10	79.1	179
	Banner	116	100	17	138	38	5.14	79.5	230
	CDC Forest**	127	119	9	160	41	5.27	77.9	349
	Compass	110	98	13	123	25	5.33	82.0	171
	Ginny 2	133	120	10	162	42	5.27	78.9	290
	Hampton	133	127	7	178	51	5.75	81.7	297
	Passion	164	145	20	234	89	5.39	79.9	190
	Striker	117	109	8	146	37	5.77	80.6	301
Yellow	CDC Leroy**	110	97	13	126	28	5.07	77.5	333
	CDC Meadow	125	116	9	148	32	5.35	79.9	205
	Hyline**	109	99	10	134	35	5.47	79.2	334
	Montech**	97	91	6	119	28	5.35	77.4	332
	Orchestra**	143	128	16	174	47	5.24	78.8	310
	Puns 0667**	129	124	4	202	78	5.77	77.9	178
	Salamanca	124	116	8	164	48	5.78	80.3	326
	Spider**	139	133	6	185	52	5.54	79.6	275
	Thunderbird**	114	109	5	150	40	5.27	78.3	276
	Treasure**	132	124	8	178	54	5.34	78.0	307
	Unknown	122	112	10	155	43	5.30	78.9	338
Winter Green	Keystone**	114	112	2	162	50	6.23	83.9	183
	Vail	114	104	9	147	42	5.84	81.6	175
Winter Yellow	Blaze	130	124	5	178	53	6.26	81.4	210
	Goldenwood**	96	91	5	113	22	5.60	81.5	139

**Only one sample of cultivar tested

Functionality Properties (Tables 15-17)

Functionality property evaluation was new in 2022 and were run again in 2023. These tests include emulsion activity and stability, foaming capacity and stability, water holding capacity and oil holding capacity. The emulsion activity and stability for all samples ranged from 53-58% and 54-59% (Table 15). However, the peas from the various classes had the same emulsion activity and stability (Table 16). Furthermore, no one cultivar had emulsion activity and stability values that were substantially different from others. In contrast to emulsion activity, foaming capacity varied to a greater extent (120-247%). Differences in foaming capacity among different classes of peas were not observed (Table 16); however, less variability was observed in the foam stability of the peas from different market classes. In contrast, at the cultivar/variety level differences in foaming capacity and stability were evident (Table 17). Among cultivars, CDC Leroy had the highest water holding capacity while Compass and Vail had the lowest. In oil holding capacity, only minor differences were present with Orchestra having the highest value (0.33g/g) and Vail the lowest (0.14 g/g).

Table 15. Functional properties of dry pea grown in the USA, 2022-2023.

Functional Properties	Year 2023 Range	2023 Mean (SD)	2022 Mean (SD)
Emulsion Activity (%)	53-58	56 (1)	59 (1)
Emulsion Stability (%)	54-59	57 (1)	58 (2)
Foaming Capacity (%)	120-247	166 (29)	215 (27)
Foam Stability (%)	33-91	71 (11)	62 (10)
Water Holding Capacity (g/g)	0.91-1.71	1.30 (0.21)	1.28 (0.12)
Oil Holding Capacity (g/g)	0.1-0.35	0.21 (0.06)	0.37 (0.27)

Table 16. Functional properties of different market classes of dry pea grown in the USA, 2022-2023.

Physical Parameter	Mean (SD) of Green Pea 2023	2022
Emulsion Activity (%)	56 (1)	59 (1)
Emulsion Stability (%)	57 (1)	58 (1)
Foaming Capacity (%)	165 (27)	221 (33)
Foam Stability (%)	73 (9)	58 (9)
Water Holding Capacity (g/g)	1.3 (0.22)	1.34 (0.14)
Oil Holding Capacity (g/g)	0.20 (0.06)	0.17 (0.04)
Physical Parameter	**Mean (SD) of Yellow Pea 2023**	**2022**
Emulsion Activity (%)	56 (0.7)	59 (1)
Emulsion Stability (%)	57 (0.8)	59 (1)
Foaming Capacity (%)	168 (30)	208 (25)
Foam Stability (%)	68 (10)	67 (14)
Water Holding Capacity (g/g)	1.4 (0.16)	1.31 (0.10)
Oil Holding Capacity (g/g)	0.22 (0.06)	0.16 (0.03)
Physical Parameter	**Mean (SD) of Winter Pea 2023**	**2022**
Emulsion Activity (%)	56 (1)	58 (1)
Emulsion Stability (%)	57 (0.7)	58 (3)
Foaming Capacity (%)	162 (33)	215 (26)
Foam Stability (%)	72 (18)	63 (8)
Water Holding Capacity (g/g)	1.1 (0.13)	1.22 (0.11)
Oil Holding Capacity (g/g)	0.18 (0.05)	0.68 (0.15)

Table 17. Mean functional properties of dry pea cultivars grown in the USA, 2023.

Market Class	Cultivar	Emulsion Activity (%)	Emulsion Stability (%)	Foaming Capacity (%)	Foam Stability (%)	Water Holding Capacity (g/g)	Oil Holding Capacity (g/g)
Green	Aragon**	56	56	183	73	1.3	0.16
	Arcadia	56	56	138	64	1.5	0.17
	Ariel**	56	56	157	83	1.1	0.23
	Banner	57	57	195	76	1.1	0.16
	CDC Forest**	57	57	150	59	1.3	0.23
	Compass	57	57	212	74	1.0	0.17
	Ginny 2	56	57	147	62	1.5	0.24
	Hampton	56	57	160	78	1.4	0.21
	Passion	55	56	167	76	1.1	0.19
	Striker	56	56	156	81	1.4	0.24
Yellow	CDC Leroy**	56	55	120	63	1.7	0.22
	CDC Meadow	57	56	198	80	1.3	0.20
	Hyline**	57	58	153	59	1.5	0.26
	Montech**	55	55	157	57	1.2	0.13
	Orchestra**	56	57	153	70	1.4	0.33
	Puns 0667**	55	57	170	65	1.2	0.28
	Salamanca	57	57	140	58	1.4	0.23
	Spider**	57	57	167	66	1.3	0.15
	Thunderbird**	57	56	157	66	1.6	0.26
	Treasure**	56	58	160	79	1.3	0.26
	Unknown	56	57	182	72	1.4	0.20
Winter Green	Keystone**	54	57	140	78	1.2	0.16
	Vail	56	57	157	78	1.0	0.14
Winter Yellow	Blaze	56	57	149	79	1.2	0.21
	Goldenwood**	58	58	233	33	1.1	0.17

**Only one sample of cultivar tested

Lentil Quality Results

Sample distribution

A total of 47 lentil samples were collected from Montana and Washington between August 2023 to November 2023. Samples were delivered to SDSU between September 2023 and February 2024. Growing location, number of samples, market class, and genotype details of these dry pea samples are provided in Table 18. CDC Richlea (12) and CDC Viceroy (6) accounted for the majority of the lentil samples. However, 18 unknown cultivars were included in the sample evaluation for 2023.

Table 18. Description of lentils used in the 2023 pulse quality survey.

State	No. of Samples	Market Class	Cultivars	
Montana	29	Green	CDC Richlea	CDC Viceroy
			Eston	Laird
		Red	Crimson	
Washington	18	Green	Brewer	
		Spanish Brown	Pardina	

Proximate composition of lentils (Tables 19-21)

Moisture

The moisture content of lentils ranged from 7.1 to 11.7% in 2023 (Table 19). The mean moisture content (9.0%) was slightly higher than the 5- and 10-year mean moisture content of 8.0 and 8.4%, respectively. In general, the mean moisture in 2023 was higher than mean moisture values from 2020-2022, but lower than lentils from 2019. Overall, all samples evaluated had moisture contents below the 13-14% recommended maximum for general storability. The moisture contents of the different market classes were between 7.8 and 9.4% (Table 20). The green and red lentils had mean moisture contents of 9.4% and 9.0%, respectively, while Spanish brown lentils had moisture contents of 7.8%. The green lentils from 2023 had higher moisture contents than the 5- and 10-year mean moisture contents of 8.0 and 8.4%, respectively. The mean moisture content of green lentils from 2023 was similar to the green lentils from 2019. Spanish brown lentils had a mean moisture content that was slightly lower than the 5-year mean value, but comparable to lentils from 2020 and 2021. The red lentils had a mean moisture content that was slightly higher than the 5- and 10-year mean moisture contents of 8.7 and 8.6%, respectively.

The highest moisture contents were observed in the CDC Richlea (10.0%) cultivar (i.e., green lentil) while the Pardina (8.0%) cultivar (i.e., Spanish brown lentil) had the lowest moisture content (Table 21).

Ash

The ash content of lentils ranged from 2.0 to 3.4% with a mean of 2.5% (Table 19). The mean ash content of lentils grown in 2023 was only slightly lower than the 5- and 10-year mean ash contents of 2.6%. Ash content is a general indicator of minerals present. The mean ash contents of the green, red, and Spanish brown market classes were 2.5, 2.8, and 2.7%, respectively (Table 20). In general, the different classes of lentils had mean ash values that were comparable to their respective 5- and 10-year mean ash contents. The Brewer cultivar had the highest (3.0%) mean ash content among cultivars evaluated (Table 21).

Fat

The fat content of lentils ranged from 0.7 to 1.3% with a mean of 1.0% (Table 19). The fat content was lower than the 5-year mean fat content of 1.4%. The mean fat content of lentils from 2023 was like fat content in lentils from 2019 to 2022, where the difference in fat content was approximately ± 0.1% from the 1% observed in 2023. Literature reports indicate that lentils have fat contents between 1 and 3%; therefore, the fat content of the lentils grown in 2023 falls at the lower end of the range reported by others. Only minor differences in fat percentages were observed between the different market classes (Table 20). Minimal difference in the mean fat contents was observed among the cultivars (Table 21). However, small variation (0.9-1.3%) was observed among the samples with CDC Richlea having the lowest fat content and Laird having the highest fat content. Like previous years, this data supports the consistent low-fat content of lentils.

Table 19. Proximate composition of lentils grown in the USA, 2019-2023 plus 5- and 10-year mean values.

Proximate Composition (%)*	2023 Range	2023 Mean (SD)	Mean (SD) 2022	2021	2020	2019	5-year	10-year
Moisture	7.1-11.7	9.0 (1.3)	8.5 (0.6)	8.0 (0.9)	8.2 (1.2)	9.8 (1.6)	8.0 (0.7)	8.4 (1.6)
Ash	2.0-3.4	2.5 (0.3)	2.8 (0.2)	2.7 (0.3)	2.6 (0.4)	2.4 (0.3)	2.6 (0.2)	2.6 (0.1)
Fat	0.7-1.3	1.0 (0.2)	1.0 (0.1)	0.9 (0.1)	1.3 (0.5)	1.1 (0.3)	1.4 (0.7)	nd
Protein	19.8-29.1	24.2 (1.7)	24.9 (1.4)	24.5 (1.3)	24.8 (1.5)	24.3 (1.5)	24.6 (0.3)	23.8 (1.0)
Total Starch	32.4-45.2	41.1 (2.3)	40.9 (1.7)	43.0 (2.0)	44.4 (2.8)	42.8 (1.6)	43.0 (1.4)	43.8 (4.1)

*composition is on an "as is" basis; nd = not determined due to test not being performed for 10 years.

Table 20. Proximate composition of different market classes of lentils grown in the USA, 2019-2023 plus 5- and 10-year mean values.

Market Class	Proximate Composition (%)	Mean (SD) 2023	2022	2021	2020	2019	5-Year	10-Year
Green	Moisture	9.4 (1.2)	8.6 (0.6)	8.1 (0.9)	8.5 (1.2)	10.3 (1.8)	8.9 (0.8)	8.8 (1.6)
	Ash	2.5 (0.3)	2.9 (0.1)	2.7 (0.3)	2.5 (0.5)	2.4 (0.2)	2.6 (0.2)	2.6 (0.2)
	Fat	1.0 (0.2)	1.0 (0.1)	0.9 (0.1)	1.3 (0.5)	1.1 (0.4)	1.4 (0.8)	nd
	Protein	24.3 (1.9)	25.7 (1.3)	24.9 (1.3)	24.5 (1.6)	24.8 (1.5)	24.8 (0.6)	23.7 (1.3)
	Total Starch	40.4 (2.2)	39.0 (1.2)	42.0 (1.3)	44.7 (2.9)	42.1 (1.4)	42.4 (2.2)	43.7 (4.5)
Red	Moisture	9.0 (0)	*	10.6 (0)	7.9 (1.2)	8.8 (1.0)	8.7 (1.2)	8.6 (1.6)
	Ash	2.8 (0)	*	2.5 (0)	2.7 (0.3)	2.4 (0.3)	2.6 (0.2)	2.7 (0.2)
	Fat	1.2 (0)	*	0.8 (0)	1.3 (0.4)	1.2 (0.3)	1.5 (0.6)	nd
	Protein	25.4 (0)	*	25.1 (0)	26.3 (0.9)	24.7 (0.8)	25.3 (0.8)	24.7 (1.1)
	Total Starch	42.6 (0)	*	39.2 (0)	43.6 (4.1)	42.8 (0.7)	42.5 (1.9)	44.3 (4.7)
Spanish Brown	Moisture	7.8 (0.4)	8.5 (0.6)	7.6 (0.4)	7.5 (0.8)	9.8 (1.2)	8.2 (1.0)	nd
	Ash	2.7 (0.3)	2.8 (0.2)	2.8 (0.4)	2.6 (0.1)	2.4 (0.3)	2.6 (0.2)	nd
	Fat	1.1 (0.1)	1.0 (0.1)	0.9 (0.1)	1.6 (0.4)	1.1 (0.2)	1.3 (0.5)	nd
	Protein	24.0 (0.4)	24.4 (1.2)	23.9 (1.3)	24.9 (0.9)	23.5 (1.2)	24.2 (0.5)	nd
	Total Starch	42.7 (1.5)	41.8 (1.0)	44.6 (1.5)	43.9 (1.8)	43.9 (1.5)	43.7 (1.1)	nd

* no red lentils evaluated in 2022, 5 and 10 year determination was done on 2017-21 and 2012-21 for red lentils, respectively; nd = not determined due to test not being performed for 10 years.

Protein

Protein content of lentils ranged from 19.8 to 29.1% with a mean value of 24.2% (Table 19). The mean protein content of lentils grown in 2023 was higher than the 10-year mean protein content of 23.8% but lower than the 5- year mean value of 24.6%. The protein content of the red market class was higher than the mean protein for green and Spanish brown lentils (Table 20). Red lentils had a mean protein content (25.4%) that was greater than the 5- and 10-year mean values. In contrast, the mean protein contents of the green and Spanish brown lentils were lower than the 5- and 10-year mean protein values (Table 20). However, the mean protein content of the green lentils from 2023 was higher than the 10-year mean protein contents. The Brewer and Eston (green) cultivars had the highest protein percentage (25.9%) among tested cultivars (Table 21). The Laird lentils had the lowest protein content (22.8%) in 2023.

Table 21. Mean proximate composition of lentil cultivars grown in the USA in 2023.

Market Class	Cultivar	Concentration (%) Moisture	Ash	Fat	Protein	Starch
Green	Brewer**	8.5	3.0	1.2	25.9	32.4
	CDC Richlea	10.0	2.4	0.9	23.1	41.6
	CDC Viceroy	9.6	2.2	1.0	25.3	39.9
	Eston	9.5	2.3	1.1	25.9	38.9
	Laird	9.8	2.8	1.3	22.8	41.1
	Unknown	8.2	2.6	1.1	25.3	40.2
Red	Crimson**	9.0	2.8	1.2	25.4	42.6
Spanish Brown	Pardina	8.0	2.8	1.0	24.6	41.5
	Unknown	7.8	2.7	1.1	23.9	42.9

**Only one sample of cultivar tested

Total starch

Total starch content of lentils ranged from 32.4 to 45.2%, with a mean of 41.1% (Table 19). The mean total starch percentage of lentils grown in 2023 was lower than starch percentage in lentils from the previous five and ten years. The mean 5- and 10-

year starch contents were 43.0 and 43.8%, respectively. The mean starch content in peas grown in 2023 was approximately the same as the starch content of peas from 2022 but 2 to 3 percentage points lower than peas from 2019-2021. The Spanish brown (42.7%) and red (42.6%) classes had higher starch content than the green lentils (40.4%) (Table 20). The green and Spanish brown lentils produced in 2023 had mean starch contents that were lower than lentils from other crop years except 2022. The starch content of 40.4% for the green lentils from 2023 was substantially lower than the starch 5- and 10-year mean starch contents of 42.4 and 43.7%, respectively. In the Spanish brown market class, the mean starch content in 2023 was 42.7% while the 5-year mean starch content was 43.7% (Table 20). The total starch content (42.6%) of the red lentils was comparable to the 5-year mean value (42.5%) but lower than the 10-year mean value (44.3%). The highest mean starch content was observed in Crimson (red) cultivar at 42.6% (Table 21). The Brewer cultivar had the lowest starch content (32.4%) among known cultivars evaluated. This cultivar also had the highest protein content and thus supports the assumption that the higher protein percentage contributed to the lower starch percentage.

Physical parameters of lentils (Tables 22-24)

Test weight, 1000 seed weight, water hydration capacity, percentage unhydrated seeds, swelling capacity, cooking firmness and color represent the physical parameters used to define physical quality. **Test weight** ranged from 58.9-69.1 lbs./Bu with a mean of 63.5 lbs./Bu. This mean value was the same as the 5-year mean test weight but higher than the 10-year mean test weight of 62.7 lbs./Bu (Table 22). The mean test weight of lentils in the Spanish brown market class was approximately 1 and 2 percentage points higher than test weights of lentils from the red and green classes (Table 23). The mean test weight for lentils in the Spanish brown market class in 2023 was slightly lower than the 5-year mean test weight. In contrast, the lentils in the green and red classes from 2023 had higher mean test weight compared to the 5- and 10-year mean test weights. The highest test weight of 65.8 lbs./Bu was observed in the Eston cultivar while Brewer had the lowest test weight of 60.3 lbs./Bu (Table 24).

Table 22. Physical parameters of lentils grown in the USA, 2019-2023.

Physical Parameters	2023		Mean (SD)					
	Range	Mean (SD)	2022	2021	2020	2019	5-year	10-year
Test Weight (lb/Bu)	58.9-69.1	63.5 (2.3)	64.1 (2.6)	64.3 (2.9)	64.3 (2.0)	62.4 (2.5)	63.5 (0.8)	62.7 (1.1)
1000 Seed Wt (g)	32-78	52 (12)	40 (11)	45 (13)	48.0 (10.0)	42.8 (10.8)	44 (3)	44 (2)
Water Hydration Capacity (%)	56-135	97 (13)	94 (8)	87 (8)	91 (21)	91 (8)	92 (4)	96 (9)
Unhydrated Seeds (%)	0-46	10 (10)	9 (7)	4 (4)	5 (6)	4 (4)	5 (3)	4 (3)
Swelling Capacity (%)	100-222	156 (23)	101 (18)	98 (15)	117 (21)	143 (15)	118 (23)	nd
Cooked Firmness (N/g)	12.2-29.2	17.8 (3.6)	17.9 (4.1)	19.8 (4.2)	19.9 (4.3)	15.8 (4.8)	17.7 (2.3)	nd

nd = not determined due to test not being performed for 10 years.

The range and mean **1000 seed weight** of lentils grown in 2023 were 32 to 78 g and 52.0 g, respectively (Table 22). The mean 1000 seed weight was significantly higher than the 5- and 10-year mean values of 44 g. This data supports larger seed size of the lentils in 2023. Lentils from the green market class had a mean 1000 seed weight of 57 g, which is higher than the mean 1000 seed weights for green lentils grown in 2019-2021. Furthermore, the mean 1000 seed weight is higher than the 5- and 10-year mean values (Table 23). The red lentils from 2023 had higher mean 1000 seed weights than the 5- and 10-year mean 1000 weight mean values. A higher (39 g) 1000 seed weight was observed in 2023 compared to the 5-year mean value of 37 g. The lentils weights from the green and Spanish brown classes supports larger seed size compared to previous evaluations. The CDC Viceroy cultivar had the lowest (46 g) 1000 seed weight while Laird had the highest (77 g) 1000 seed weight among lentils from 2023 (Table 24).

Water hydration capacity of lentils ranged from 56 to 135%, with a mean of 97% (Table 22). The mean water hydration capacity value of lentils from 2023 was comparable to the lentils that made up the 10-year mean water hydration capacity (96%). However, the mean water hydration capacity (97%) was higher than the lentils that made up the 5-year mean water hydration capacity. The water hydration capacity (107%) was highest for the red lentils while the Spanish brown market classes had the lowest (93%) water hydration capacities (Table 23). The green lentils from 2023 had water hydration capacities that were significantly lower than the 5- and 10-year mean values. Red lentils had a mean water hydration capacity (107%) that was lower than the 5-year mean value (112%) but higher than the 10-year mean value (103%). Spanish brown lentils had slightly higher (93%) water hydration capacity to the 5-year mean value of 89% (Table 23). The mean water hydration capacity ranged from 92% to 107% in CDC Viceroy and Crimson cultivars, respectively (Table 24).

Table 23. Physical parameters of different market classes of lentils grown in the USA, 2019-2023 plus 5- and 10-year mean values.

Market class	Physical Parameter	Mean (SD)						
		2023	2022	2021	2020	2019	5-Year	10-Year
Green	Test Weight (lb/Bu)	62.9 (2.3)	61.0 (1.8)	62.3 (2.5)	63.6 (1.8)	61.8 (2.4)	62.1 (0.9)	62.2 (0.8)
	1000 Seed Wt (g)	57 (9)	55 (3)	51 (13)	51 (10)	46 (12)	50 (3)	47 (6)
	Water Hydration Capacity (%)	98 (12)	99 (7)	85 (9)	88 (11)	93 (6)	103 (24)	101 (19)
	Unhydrated Seeds (%)	9 (11)	3 (3)	3 (3)	6 (7)	2 (2)	3 (2)	3 (3)
	Swelling Capacity (%)	164 (19)	116 (19)	97 (13)	117 (18)	145 (11)	123 (20)	nd
	Cooked Firmness (N/g)	17.2 (3.0)	16.6 (1.4)	19.7 (4.7)	19.2 (4.2)	15.5 (5.3)	17.1 (2.3)	nd
Red	Test Weight (lb/Bu)	64.1 (0.0)	*	64.7 (0)	63.9 (2.5)	64.2 (0.4)	63.5 (1.2)	62.6 (2)
	1000 Seed Wt (g)	49 (0)	*	63 (0)	43 (9)	36.8 (6)	44 (11)	43 (9)
	Water Hydration Capacity (%)	107 (0)	*	93 (0)	126 (41)	84 (8)	112 (20)	103 (17)
	Unhydrated Seeds (%)	2 (0)	*	3 (0)	5 (6)	8 (1)	4 (3)	4 (2)
	Swelling Capacity (%)	177 (0)	*	128 (0)	138 (35)	140 (5)	136 (6)	nd
	Cooked Firmness (N/g)	12.2 (0.0)	*	19.6 (0)	21.7 (5.3)	14.8 (5.7)	17.2 (3.2)	nd
Spanish Brown	Test Weight (lb/Bu)	65.0 (1.7)	65.7 (1.0)	66.7 (0.7)	66.1 (1.0)	62.4 (2.0)	65.3 (1.7)	nd
	1000 Seed Wt (g)	39 (6)	32 (2)	35 (3)	42 (4)	43 (7)	37 (5)	nd
	Water Hydration Capacity (%)	93 (15)	92 (8)	88 (6)	81 (13)	91 (8)	89 (5)	nd
	Unhydrated Seeds (%)	14 (6)	12 (6)	6 (3)	5 (4)	3.9 (6)	7 (3)	nd
	Swelling Capacity (%)	132 (19)	93 (12)	97 (16)	109 (15)	143 (21)	116 (23)	nd
	Cooked Firmness (N/g)	20.0 (4.0)	18.5 (4.9)	19.8 (4.0)	21.7 (3.9)	15.8 (2.8)	18.3 (2.6)	nd

* no red lentils evaluated in 2022; 5 and 10 year determination was done on 2017-21 and 2012-21 for red lentils, respectively; nd = not determined due to test not being performed for 10 years.

Unhydrated seed percentage ranged from 0 to 46% with a mean of 10 %, which is greater than the 5- and 10-year mean of 5 and 4%, respectively (Table 22). Many of the samples had unhydrated seed rates around 2%, which likely contributed to 10% unhydrated seed rate in 2023 by offsetting the few samples with high unhydrated levels. The mean unhydrated seeds in varied from 2% in red lentils to 14% in Spanish Brown (Table 23). The green lentils from 2023 had mean unhydrated seed percentage that was higher than the 5- and 10-year mean unhydrated seed percentage or 3%. For the Spanish brown lentils, the unhydrated seed count in was significantly higher (14%) than the 5-year mean unhydrated seed percentage (4%). In contrast, the red lentils had unhydrated seed rates that were lower than the 5- and 10-year mean unhydrated seed rate. The Eston (green) and Crimson (red) cultivars had the lowest unhydrated seed percentage at 2% while the CDC Viceroy cultivar had the highest mean unhydrated seed weight of 19% (Table 24). The unhydrated seed percentage follows the trends of from 2022 where the Spanish brown seeds tended to hydrate less than the green lentils.

The **swelling capacity** of all lentils ranged from 100 to 222%, with a mean value of 156% (Table 22). The mean swelling capacity from 2023 samples were comparable to the lentils from 2019 but significantly higher than that of lentils from the previous years, including the 5-year mean swelling capacity. The mean swelling capacity of lentils from the green market class was 164 % (Table 23). The swelling capacity of the green lentils was most comparable to lentils from 2019 but was significantly higher than the 5-year mean swelling capacities of 123%. The swelling capacity of the red lentils was significantly higher than lentils from previous years and the 5-year mean swelling capacities of 136%. The mean swelling capacity (132%) of the Spanish brown lentils in 2023 was similar to the mean swelling capacity (143%) for the Spanish brown lentils from 2019. Additionally, the mean swelling capacity of the Spanish brown lentils in 2023 was significantly higher than the 5-year mean swelling capacity (Table 23). The greatest swelling capacity (177%) was observed in the Crimson cultivar while the Laird cultivar lentil had the lowest (130%) mean swelling capacity (Table 24). The reason for this might be due to the low water uptake as supported by low water hydration capacity.

Table 24. Mean physical parameters of USA lentil cultivars grown in 2023.

Market Class	Cultivar	Test Weight (lb/bu)	1000 Seed Wt (g)	Water Hydration Capacity (%)	Unhydrated Seeds (%)	Swelling Capacity (%)	Cooked Firmness (N/g)
Green	Brewer**	60.3	54	100	15	134	23.6
	CDC Richlea	63.1	61	95	9	171	16.6
	CDC Viceroy	65.6	46	92	19	173	17.0
	Eston	65.8	46	98	2	155	16.0
	Laird	61.7	77	98	4	130	15.8
	Unknown	60.3	59	108	6	158	18.6
Red	Crimson**	64.1	49	107	2	177	12.2
Spanish Brown	Pardina	65.0	48	94	7	142	20.9
	Unknown	65.1	37	92	15	130	19.9

**Only one sample of cultivar tested

The **cooked firmness** of all lentils ranged from 12.2 to 29.2 N/g with a mean value of 17.8 N/g (Table 22). The lentils from 2023 had similar cooked firmness values to lentils from 2022 and to the 5-year mean cooked firmness (17.7 N/g). The cooked firmness of lentils from 2023 fell in between the values from 2020 and 2021(~20 N/g) and 2019 (~15.5 N/g). The cooked firmness of lentils was not substantially different between the green and Spanish brown classes; however, the red lentils had cooked firmness values that were 5 to 8 percentage points lower than the values from the other classes (Table 23). The lentils from the green market class had a mean cooked firmness value (17.2 N/g) that was comparable to the 5-year mean cooked firmness (17.1 N/g). In contrast, the red lentils had mean cooked firmness of 12.2 N/g, which is 5 N/g less than the 5-year mean value. The mean cooked firmness (20 N/g) of Spanish brown lentils was nearly 2 N/g higher for the lentils from 2023 compared to the 5-year mean value. Among the cultivars, Brewer had the highest cooked firmness value while Crimson had the lowest cooked firmness (Table 24).

Color quality was measured using L*, a*, and b* values and from these values a color difference can be determined on lentils before and after soaking (Table 25). The color quality for all lentils in 2023 indicated that the lentils had lower L* values than in lentils from previous years except 2021. This data indicates that the lentils from the 2023 crop year were darker in color than those from recent years. However, the L* value of the green lentils was higher than the 5- and 10-year mean L* value which support lighter color compared to long term averages. The L* values of the red closely matched the 5- and 10-year mean L* values. The Spanish brown lentils had a mean L* value that was greater than the 5-year mean L* value (Table 25). In 2023, the a* value of 1.87 indicates that the lentils were greener than the lentils from recent years except 2020. Additionally, green lentils had a* values that were lower than the 5- and 10-year mean a* values, indicating a greener lentil for the 2023 samples compared to long term mean values. The mean a* value for the Spanish brown lentils was higher than the 5-year mean a* value indicating redness. In contrast, the red lentils from 2023 had lower a* compared to the 5- and 10-year mean a* values, indicating less redness for sample from 2023. The green lentils had a lower mean b* value than the 5- and 10-year mean values suggesting the 2023 samples are less yellow in nature. The Spanish brown mean b* value for 2023 was greater than the b* value of samples from 2021 and 2022 but less than samples from 2019 and the samples that made up the 5-year mean b* value. This indicates that the lentils were a darker brown compared to the 5-year mean due to the lower yellowness of the lentil in 2023. The red lentils had significantly higher b* values in 2023, supporting a lentil with more yellow hue. The color of the lentils changed after the soaking process. Green lentil became lighter as evidenced by the slightly higher L* values while the red and Spanish brown became darker compared to pre-soaked lentils (Table 25). In the green lentils, the decreased a* value indicated an increase in greenness of the lentils after soaking. In contrast, the other lentil classes had increased a* values, indicating an increase in redness. Lentils from all market classes became more yellow (i.e., increased b* value) after soaking. The color difference in lentil samples was comparable between market classes (Table 25). However, the color difference in red lentils was slightly higher. Overall, the colors of lentils in 2023

Table 25. Color quality of lentils grown in the USA before and after soaking, 2020-2023 plus 5- and 10-year values.

Color Scale	Mean (SD) of green lentils											
	Before Soaking						After Soaking					
	2023	2022	2021	2020	5-Year	10-year	2023	2022	2021	2020	5-Year	10-Year
L (lightness)	57.75 (1.00)	58.82 (0.77)	57.10 (0.96)	59.75 (1.45)	55.54 (4.72)	56.93 (4.08)	58.51 (1.19)	59.02 (0.45)	56.69 (2.59)	60.15 (3.93)	57.30 (2.77)	59.12 (3.72)
a (red-green)	1.87 (1.44)	2.72 (0.82)	3.20 (1.85)	0.83 (1.05)	2.32 (1.62)	2.74 (1.67)	0.12 (1.83)	1.20 (1.33)	2.00 (1.35)	-0.12 (4.00)	1.19 (1.88)	1.57 (2.00)
b (yellow-blue)	14.07 (7.49)	11.73 (1.13)	12.22 (2.10)	15.39 (0.95)	14.83 (3.87)	17.73 (4.56)	24.64 (1.77)	19.93 (3.04)	14.23 (3.89)	20.48 (5.52)	21.17 (5.96)	25.92 (6.83)
Color Difference	10.82 (1.45)	8.38 (1.99)	5.57 (1.48)	8.23 (4.79)	8.41 (1.83)	nd						
Color Scale*	**Mean (SD) of red lentils**											
	Before Soaking						After Soaking					
	2023	2022	2021	2020	5-Year	10-Year	2023	2022	2021	2020	5-Year	10-Year
L (lightness)	51.17 (0)	**	53.60 (0)	55.13 (2.32)	50.18 (4.51)	51.87 (4.56)	50.36 (0)	**	54.52 (0)	55.05 (3.93)	52.05 (3.03)	2.74 (1.67)
a (red-green)	4.14 (0)	**	3.47 (0)	2.88 (1.91)	4.90 (2.28)	4.97 (1.93)	7.60 (0)	**	5.48 (0)	5.36 (3.42)	9.29 (3.87)	9.45 (3.09)
b (yellow-blue)	17.49 (0)	**	5.29 (0)	11.07 (4.09)	11.41 (4.58)	12.15 (4.37)	18.29 (0)	**	10.21 (0)	14.67 (2.55)	20.11 (8.11)	21.69 (6.27)
Color Difference	11.37 (0)	**	5.40 (0)	7.40 (3.28)	10.77 (4.28)	nd						
Color Scale	**Mean (SD) of brown lentils**											
	Before Soaking						After Soaking					
	2023	2022	2021	2020	5- Year	10-Year	2023	2022	2021	2020	5-Year	10-Year
L (lightness)	54.98 (0.98)	54.01 (0.36)	51.11 (0.47)	51.97 (0.33)	47.86 (6.35)	nd	51.17 (1.09)	54.71 (0.73)	52.42 (1.22)	53.96 (0.44)	49.91 (6.41)	nd
a (red-green)	3.04 (0.37)	2.65 (0.23)	3.17 (0.26)	0.66 (1.48)	2.64 (1.63)	nd	3.20 (0.60)	2.20 (0.43)	2.99 (0.56)	-0.90 (0.70)	2.86 (2.85)	nd
b (yellow-blue)	7.27 (0.56)	6.78 (0.21)	6.93 (0.47)	8.60 (1.58)	8.23 (2.45)	nd	10.74 (0.60)	15.42 (1.12)	11.96 (4.85)	10.13 (1.54)	16.31 (7.58)	nd
Color Difference	10.81 (1.34)	8.69 (1.11)	5.58 (4.33)	3.53 (1.79)	9.11 (5.96)	nd						

*color scale L (lightness) axis – 0 is black and 100 is white; a (red-green) axis – positive values are red, negative values are green, and zero is neutral; and b (yellow-blue) axis – positive values are yellow, negative values are blue, and zero is neutral. Color difference = change in value before soaking and after soaking. **no red lentils evaluated in 2022; 5 and 10 year determination was done on 2017-21 and 2012-21 for red lentils, respectively; nd = not determined due to test not being performed for 10 years.

were impacted (higher value) more by soaking in comparison to lentils that made up the 5-year mean color difference value. Among the cultivars, Crimson had the lowest L* value followed by Pardina (Table 26). The highest L* was observed in the Laird green lentil. This follows expectations that the red and brown lentils would be darker than the green lentils. The L* values of lentil decreased for the red and Spanish brown lentils after soaking. In contrast, mixed results were observed in the green cultivars were L* increased after soaking in all samples except Brewer (Table 26). The green lentil cultivars became greener (i.e., reduction of the a* value) after soaking. In contrast, the Crimson and Pardina became redder in color after soaking. The increased b* values indicated that the lentils in all market classes became more yellow in color. The green lentil cultivar Eston had the highest b* value (i.e., yellowness) of the soaked lentils. This is a green coated lentil, but has a yellow cotyledon; thus, the soaking may have reduced the impact of the hull on color and resulted in increased yellowness. The change in yellowness contributed to the greatest color difference that was observed in the Eston cultivar (Table 26). The change in greenness and yellowness during soaking likely contributed to the greatest color difference in this cultivar. The color of Laird was the most stable as this cultivar had the lowest color difference value (i.e., 8.42).

Table 26. Color quality of USA lentil cultivars before and after soaking, 2023.

		Mean Color Values*						
		Before Soaking			After Soaking			Color
Market Class	Cultivar	L	a	b	L	a	b	Difference
Green	Brewer**	58.31	4.36	12.28	56.78	3.04	23.12	11.15
	CDC Richlea	57.85	1.19	14.52	58.79	-0.70	25.28	11.00
	CDC Viceroy	57.52	1.00	14.19	58.56	-1.13	25.81	11.89
	Eston	57.56	0.94	13.94	58.73	-1.24	26.20	12.54
	Laird	58.38	1.76	16.04	60.54	0.20	23.91	8.42
	Unknown	57.62	3.77	12.95	57.60	2.60	22.42	9.59
Red	Crimson**	51.17	4.14	7.49	50.36	7.60	18.29	11.37
Spanish Brown	Pardina	55.21	2.44	6.37	50.28	2.69	17.38	12.17
	Unknown	54.93	3.16	7.45	51.62	3.30	17.11	10.45

*color scale L (lightness) axis – 0 is black and 100 is white; a (red-green) axis – positive values are red, negative values are green, and zero is neutral; and b (yellow-blue) axis – positive values are yellow, negative values are blue, and zero is neutral. Color difference = change in value before soaking and after soaking. **Only one sample of cultivar tested.

Pasting properties (Tables 27-29)

Peak, hot paste and cold paste viscosities of lentils grown in 2023 were significantly lower than their respective values from lentils of other harvest years. For example, a significantly lower cold paste viscosity (151 RVU) was observed for lentils from 2023 compared to other harvest years and the 5- and 10-year mean cold paste viscosity (Table 27). The pasting temperature ranged from 76.7 to 83.2 °C, with a mean value of 79.8 °C, which is higher than the 5-year mean pasting temperature. The peak, hot paste, and cold paste viscosities were different among the market classes (Table 28). The peak, hot paste, and cold paste viscosities obtained for lentils in the red market class were lower than the lentils from the green and Spanish brown market class. This general observation was also observed in samples from previous years except 2019. This suggests a thinner final viscosity for red lentil flours compared to green and Spanish brown lentils. Pasting characteristics for all market classes in 2023 were lower than the 5-year mean viscosity values and for the green and red market classes, their values were lower than the 10-year mean viscosity values. This indicates that the lentils from 2023 produce thinner pastes and gels. As with peas, the lower starch contents may have contributed to the pasting characteristics. New in 2022 was the RVA gel firmness, which was

Table 27. Starch characteristics of lentils grown in the USA, 2019-2023 and 5- and 10-year mean values.

Starch Characteristic	2023		Means (SD)					
	Range	Mean (SD)	2022	2021	2020	2019	5-Year	10-year
Peak Viscosity (RVU)	63-265	118 (32)	124 (19)	117 (23)	142 (21)	146 (14)	134 (13)	133 (13)
Hot Paste Viscosity (RVU)	62-213	110 (26)	120 (18)	110 (23)	133 (17)	137 (11)	127 (11)	125 (11)
Breakdown (RVU)	0-52	7 (10)	4 (3)	7 (7)	9 (6)	9 (6)	7 (2)	8 (3)
Cold Paste Viscosity (RVU)	87-278	151 (39)	221 (32)	210 (50)	237 (35)	253 (28)	233 (18)	227 (21)
Setback (RVU)	2-76	39 (19)	101 (16)	100 (28)	104 (21)	117 (19)	107 (7)	102 (12)
Peak Time (Minute)	4.97-7.00	6.09 (0.58)	6.46 (0.56)	6.10 (0.76)	5.68 (0.62)	5.49 (0.52)	5.29 (0.38)	6.23 (1.34)
Pasting Temperature (°C)	76.7-83.2	79.8 (1.5)	80.2 (1.4)	80.0 (1.8)	78.9 (1.5)	77.1 (1.2)	78.8 (1.3)	nd
RVA Gel Fimness (g)	116-397	255 (75)	285 (35)	**	**	**	nd	nd

**not previously reported; nd = not determined due to test not being performed for 5 or 10 years.

run again in 2023. The gel firmness ranged from 116-397 g with a mean of 255 g (Table 27) with green lentils having the greatest gel firmness (Table 28). Overall, lentils had pasting viscosities that were lower in the 2023 harvest year compared to the 5- and 10-year mean values (Table 28).

Variability in pasting characteristics were observed among cultivars (Table 29). In the green market class, the variability among cultivars was noticeable. Brewer had the lowest peak, hot paste, and cold paste viscosities. Pardina had the highest peak, hot paste, and cold paste viscosities. The pasting viscosities of the Pardina lentils from 2023 mirror results from Pardina lentils from 2021 and 2022. Overall, lentils had pasting temperatures that were higher in the 2023 harvest year compared to the 5- and 10-year mean values (Table 28). The Spanish brown market class had lowest RVA gel firmness values while the green lentils had the highest (Table 28). Surprisingly, the red lentils had a gel firmness greater than the Spanish brown even though the cold paste viscosity was so much lower in the red lentil compared to the Spanish brown. The Laird cultivar produced the firmest (307 g) gel among samples (Table 29).

Table 28. Starch characteristic of different market classes of lentils grown in the USA, 2019-2023 and 5- and 10-year mean values.

		Mean (SD)						
Market class	Physical Parameter	2023	2022	2021	2020	2019	5-Year	10-Year
Green	Peak Viscosity (RVU)	119 (35)	110 (15)	111 (22)	146 (21)	142 (13)	131 (19)	133 (15)
	Hot Paste Viscosity (RVU)	110 (29)	105 (14)	103 (21)	135 (17)	133 (8)	122 (17)	124 (13)
	Breakdown (RVU)	9 (11)	5 (2)	8 (9)	10 (6)	8 (5)	8 (2)	9 (3)
	Cold Paste Viscosity (RVU)	148 (42)	194 (15)	193 (41)	241 (35)	242 (26)	223 (28)	224 (24)
	Setback (RVU)	38 (20)	89 (7)	90 (21)	106 (22)	109 (19)	101 (11)	100 (12)
	Peak Time (Minute)	5.97 (0.59)	6.55 (0.67)	6.11 (0.83)	5.54 (0.55)	5.53 (0.54)	5.86 (0.45)	6.10 (1.45)
	Pasting Temperature (°C)	79.4 (3.2)	81.2 (1.9)	80.6 (2.1)	78.7 (1.6)	76.8 (1.5)	78.9 (1.9)	nd
	RVA Gel Firmness (g)	272 (62)	268 (34)	**	**	**	nd	nd
Red	Peak Viscosity (RVU)	77 (0)	*	97 (0)	130 (21)	148 (9)	126 (19)	126 (24)
	Hot Paste Viscosity (RVU)	77 (0)	*	84 (0)	123 (17)	134 (6)	118 (20)	117 (18)
	Breakdown (RVU)	0 (0)	*	13 (0)	7 (6)	14 (7)	8 (5)	10 (10)
	Cold Paste Viscosity (RVU)	107 (0)	*	132 (0)	218 (39)	249 (13)	211 (46)	215 (49)
	Setback (RVU)	30 (0)	*	48 (0)	95 (23)	115 (12)	93 (27)	98 (32)
	Peak Time (Minute)	6.57 (0)	*	5.27 (0)	5.77 (0.53)	5.37 (0.36)	5.77 (0.51)	6.53 (1.76)
	Pasting Temperature (°C)	81.5 (0)	*	79.2 (0)	79.0 (1.8)	78.0 (0.7)	78.7 (0.6)	nd
	RVA Gel Firmness (g)	223 (0)	*	**	**	**	nd	nd
Spanish Brown	Peak Viscosity (RVU)	116 (22)	130 (17)	126 (24)	139 (21)	153 (13)	138 (11)	nd
	Hot Paste Viscosity (RVU)	111 (18)	127 (15)	121 (23)	132 (18)	143 (10)	132 (9)	nd
	Breakdown (RVU)	3 (2)	4 (3)	5 (4)	6 (5)	9 (6)	6 (2)	nd
	Cold Paste Viscosity (RVU)	161 (25)	234 (30)	237 (49)	235 (33)	249 (26)	242 (9)	nd
	Setback (RVU)	43 (15)	108 (16)	116 (27)	102 (16)	129 (18)	114 (10)	nd
	Peak Time (Minute)	6.40 (0.41)	6.42 (0.50)	6.16 (0.68)	6.03 (0.70)	5.45 (0.58)	6.05 (0.36)	nd
	Pasting Temperature (°C)	79.5 (0.5)	79.7 (0.5)	79.3 (1.0)	79.5 (0.8)	77.4 (0.6)	78.8 (1.0)	nd
	RVA Gel Firmness (g)	208 (93)	293 (33)	**	**	**	nd	nd

* no red lentils evaluated in 2022; 5 and 10 year determination was done on 2017-21 and 2012-21 for red lentils. **not previously measured; nd = not determined due to test not being performed for 5 or 10 years.

Table 29. Mean starch characteristics of lentil cultivars grown in the USA in 2023.

Market Class	Cultivar	Peak Viscosity (RVU)	Hot Paste Viscosity (RVU)	Breakdown (RVU)	Cold Paste Viscosity (RVU)	Setback (RVU)	Peak Time (Min)	Pasting Temperature (°C)	RVA Gel Firmnes (g)
Green	Brewer**	63	62	1	87	25	7.00	81.5	116
	CDC Richlea	136	125	11	170	45	5.77	78.7	305
	CDC Viceroy	115	109	6	144	34	6.08	79.3	295
	Eston	84	81	3	101	20	6.04	80.5	256
	Laird	124	113	11	139	26	5.57	77.0	307
	Unknown	112	101	10	142	41	6.15	80.7	212
Red	Crimson**	77	77	0	107	30	6.57	81.5	223
Spanish Brown	Pardina	123	121	2	174	53	6.07	79.3	274
	Unknown	114	109	4	158	41	6.47	79.5	195

**Only one sample of cultivar tested.

Functional properties (Tables 30-32)

Functionality property evaluation was completed for the second time in 2023. These tests include emulsion activity and stability, foaming capacity and stability, water holding capacity and oil holding capacity. The emulsion activity and stability for all lentil samples ranged from 53-57% and 54-58% (Table 30). However, the lentils from the various market classes had comparable emulsion activity and stability (Table 31). Furthermore, no one cultivar had emulsion activity and stability values that were substantially different from others (Table 32).

Table 30. Functional properties of lentils grown in the USA, 2022-2023.

	2023		2022
Functional Properties	Range	Mean (SD)	Mean (SD)
Emulsion Activity (%)	53-57	55 (1)	59 (1)
Emulsion Stability (%)	54-58	56 (1)	59 (2)
Foaming Capacity (%)	120-260	180 (37)	205 (45)
Foam Stability (%)	42-89	76 (9)	67 (14)
Water Holding Capacity (g/g)	1.01-1.77	1.27 (0.14)	1.30 (0.16)
Oil Holding Capacity (g/g)	0.06-0.34	0.16 (0.06)	0.40 (0.28)

In contrast to emulsion activity, foaming capacity varied to a greater extent (120-260%). Differences in foaming capacity among different classes of lentils was observed (Table 31), with the red lentils having mean foaming capacities that were approximately 40 to 70 percentage points higher than the mean foaming capacity of the green and Spanish brown lentils, respectively. In contrast, the Spanish brown lentils had foam stability that were approximately 6 to 7 percentage points higher than the foaming stability of the green and red lentils. The Crimson cultivar had significantly higher foaming capacity (227%) compared to other cultivars (Table 32). However, Brewer had the highest foam stability. The Pardina cultivar had higher water holding capacity compared to the other cultivars. For oil holding capacity, Brewer had a slightly higher value compared to the other samples.

Table 31. Functional properties of different market classes of lentils grown in the USA, 2022 and 2023.

Market Class	Functional Properties	Mean (SD) 2023	Mean (SD) 2022
Green	Emulsion Activity (%)	55 (1)	58 (1)
	Emulsion Stability (%)	56 (1)	59 (2)
	Foaming Capacity (%)	189 (37)	189 (36)
	Foam Stability (%)	74 (9)	71 (12)
	Water Holding Capacity (g/g)	1.22 (0.10)	1.28 (0.11)
	Oil Holding Capacity (g/g)	0.16 (0.07)	0.29 (0.21)
Red	Emulsion Activity (%)	54 (0)	*
	Emulsion Stability (%)	55 (0)	*
	Foaming Capacity (%)	227 (0)	*
	Foam Stability (%)	73 (0)	*
	Water Holding Capacity (g/g)	1.19 (0)	*
	Oil Holding Capacity (g/g)	0.15 (0)	*
Spanish Brown	Emulsion Activity (%)	56 (1)	58 (1)
	Emulsion Stability (%)	56 (1)	59 (2)
	Foaming Capacity (%)	151 (16)	189 (36)
	Foam Stability (%)	80 (6)	71 (12)
	Water Holding Capacity (g/g)	1.41 (0.16)	1.28 (0.11)
	Oil Holding Capacity (g/g)	0.17 (0.05)	0.29 (0.21)

*No red lentils evaluated in 2022

Table 32. Mean functional properties of lentil cultivars grown in the USA, 2023.

Market Class	Cultivar	Water Holding Capacity (g/g)	Oil Holding Capacity (g/g)	Emulsion Activity (%)	Emulsion Stability (%)	Foaming Capacity (%)	Foam Stability (%)
Green	Brewer**	1.32	0.19	56	56	170	86
	CDC Richlea	1.21	0.16	55	56	203	76
	CDC Viceroy	1.19	0.17	55	57	194	73
	Eston	1.16	0.11	55	56	203	70
	Laird	1.28	0.12	54	56	170	73
	Unknown	1.25	0.19	56	57	163	73
Red	Crimson**	1.19	0.15	54	55	227	73
Spanish Brown	Pardina	1.69	0.14	56	56	163	75
	Unknown	1.36	0.18	56	56	149	81

**Only one sample of cultivar tested.

Chickpea Quality Results

Sample distribution

A total of 78 chickpea samples were collected from Idaho, Montana, North Dakota, Oregon, and Washington between August 2023 to November 2023. Samples were delivered to SDSU between September 2023 and February 2024. Growing location, number of samples, market class, and genotype details of these dry chickpea samples are provided in Table 33. Royal (11), Sawyer (11), CDC Frontier (13) and Sierra (18) accounted for most of the chickpea evaluated.

Table 33. Description of chickpea samples used in the 2023 pulse quality survey.

State	No. of Samples	Market Class	Cultivars	
Idaho	5	Kabuli	CDC Frontier	Royal
			Sierra	
Montana	31	Kabuli	CDC Frontier	CDC Orion
			Kasin	Marvel
			Quinn	Sawyer
			Sierra	
North Dakota	9	Kabuli	CDC Frontier	CDC Orion
			Kasin	
Oregon	1	Kabuli	Sierra	
Washington	32	Kabuli	CDC Frontier	Dylan
			Nash	Royal
			Sawyer	Sierra

Proximate composition of chickpea (Tables 34-35)

The **moisture content** of chickpeas ranged from 6.2 to 14.3% in 2023 (Table 34). The mean moisture content of the samples was 8.8%, which is lower than the 5-year mean of 9.0%. However, chickpeas grown in 2023 had approximately the same mean moisture value as the samples from crop years 2021, 2022, and the 10- year mean moisture content (8.5%). This supports that the long-term mean moisture content of the chickpea from the region is consistent. Only one sample exceeded the 13-14% moisture threshold for proper storage. CDC Frontier and Kasin had the highest mean moisture content at 9.6% while the Royal had the lowest moisture content (8.0%) among all chickpeas (Table 35).

The **ash content** of chickpeas ranged from 2.0 to 3.2% with a mean of 2.8% (Table 34). The mean ash content of chickpeas grown in 2023 was comparable to ash contents of chickpea that were used in determining the 5- and 10-year mean values (Table 34). Of the known cultivars grown, CDC Orion had the lowest ash contents at 2.4%, while Dylan and Quinn had ash contents of 3.0%, thus indicating minimal variability of the ash / mineral composition (Table 35). The mean **fat content** was 5.3% with a range from 4.0 to 6.1% (Table 34). Literature reports indicate that chickpea has a fat content between 2 and 7%;

Table 34. Proximate composition of Kabuli chickpeas grown in the USA, 2019-2023 plus 5- and 10-year mean values.

Proximate Composition*	Year 2023 Range	2023 Mean (SD)	2022 Mean (SD)	2021 Mean (SD)	2020 Mean (SD)	2019 Mean (SD)	5-year Mean (SD)	10-year Mean (SD)
Moisture (%)	6.2-14.3	8.8 (1.2)	8.5 (0.9)	8.5 (0.9)	7.9 (1.1)	11.6 (2.6)	9.0 (1.4)	8.5 (2.3)
Ash (%)	2.0-3.2	2.8 (0.3)	2.9 (0.1)	3.0 (0.2)	3.0 (0.6)	2.6 (0.2)	2.8 (0.1)	2.8 (0.2)
Fat (%)	4.0-6.1	5.3 (0.4)	5.6 (0.4)	5.6 (0.3)	5.4 (0.6)	6.1 (0.5)	6.1 (0.7)	nd
Protein (%)	16.8-28.5	21.6 (2.6)	20.8 (2.3)	19.8 (1.5)	21.1 (2.0)	19.4 (1.9)	20.3 (0.8)	20.0 (0.9)
Starch (%)	33.7-46.1	40.4 (3.2)	41.3 (2.4)	40.7 (1.3)	40.8 (3.6)	40.1 (1.8)	40.6 (0.7)	42.8 (3.9)

*composition is on an "as is" basis; nd = not determined due to test not being performed for 10 years.

therefore, the fat content of chickpeas grown in 2023 fall within the range reported by others but less than the fat content recorded in previous years. Fat content was slightly lower than the 5-year mean fat content of 6.1% (Table 34). The Dylan cultivar had the highest (5.6%) fat content among chickpeas (Table 35). Furthermore, the fat content of Marvel was the lowest (5.0%) among chickpeas.

Protein content of chickpeas ranged from 16.8 to 28.5%, with a mean of 21.6% (Table 34). The mean protein content of chickpea grown in 2023 was greater than the 5- and 10-year mean protein contents of 20.3 and 20.0%, respectively. Overall, the protein content of chickpea from 2023 was most similar to the protein content of peas from 2020. Dylan had the lowest (16.8%) mean protein content while Kasin had the highest mean protein content at 26.6% (Table 35). **Total starch content** of chickpea ranged from 33.7 to 46.1%, with a mean of 40.4% (Table 33). The mean total starch content of chickpeas grown in 2023 was similar to the mean starch content observed in chickpea from the 2019 harvest year and was slightly lower than the 5-year mean of 40.6%. However, the starch content was lower than the 10- year mean value (42.8%). The Marvel cultivar had the lowest (36.0%) mean starch content while the highest (44.1%) was observed in the Dylan cultivar.

Table 35. Mean proximate composition of chickpea cultivars grown in the USA, 2023.

Cultivar	Concentration (%) Moisture	Ash	Fat	Protein	Starch
CDC Frontier	9.6	2.8	5.3	21.8	40.8
CDC Orion	9.0	2.4	5.5	22.2	37.7
Dylan**	8.3	3.0	5.6	16.8	44.1
Kasin	9.6	2.9	4.7	26.6	37.4
Marvel	8.7	2.7	5.0	22.9	36.0
Nash**	8.7	2.9	5.2	21.5	43.7
Quinn**	8.7	3.0	5.2	23.0	36.5
Royal	8.0	2.9	5.3	19.9	43.2
Sawyer	8.9	2.7	5.1	22.8	39.3
Sierra	8.6	2.9	5.5	19.6	42.2
Unknown	8.6	2.3	5.2	22.8	38.8

**Value from only one sample of cultivar tested.

Physical parameters of chickpeas (Tables 36-39)

Test weight, 1000 seed weight, water hydration capacity, percentage unhydrated seeds, swelling capacity, cooked firmness and color represent the physical parameters used to define physical quality. The data presented also include size distribution. Test weight ranged from 55.8 to 64.9 lbs./Bu with a mean of 60.6 lbs./Bu. This mean value is less than both the 5- and 10-year mean test weights (Table 36). The test weights of individual cultivars ranged from 57.5 lbs./Bu in Dylan to 63.8 lbs./Bu

Table 36. Physical parameters of Kabuli chickpeas grown in the USA, 2019-2023 plus 5- and 10-year mean values.

Physical Parameter	Year 2023 Range	2023 Mean (SD)	2022 Mean	2021 Mean	2020 Mean	2019 Mean	5-year Mean (SD)	10-year Mean (SD)
Test Weight (lb/Bu)	55.8-64.9	60.6 (2.1)	61.2 (1.9)	61.2(1.8)	61.6 (1.5)	61.0 (1.0)	61.4 (0.4)	61.2 (0.6)
1000 Seed Wt	185-570	398 (77)	477 (50)	464 (67)	417 (71)	444 (74)	443 (29)	427 (30)
Water Hydration Capacity (%)	87-135	109 (9)	105 (7)	105 (9)	108 (8)	102 (8)	104 (2)	104(3)
Unhydrated Seeds (%)	0-0	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1(1)
Swelling Capacity (%)	81-174	133 (15)	125 (12)	144 (20)	145 (17)	138 (15)	136 (9)	nd
Cooked Firmness (N/g)	13.4-27.8	20.3 (2.9)	18.6 (2.9)	19.7 (2.3)	19.6 (2.9)	20.7 (3.8)	21.3 (3.8)	nd
% of Sample Retained on 22/64 Sieve	0.0-95	53.8 (27.7)	79.5 (15.3)	69.0 (21.5)	55.6 (26.5)	64.2 (28.3)	nd	nd
% of Sample Retained on 20/64 Sieve	1.1-60.3	29.9 (16.1)	16.7 (11.9)	22.8 (12.6)	34.3 (18.6)	29.1 (20.8)	nd	nd
% of Sample Retained on 18/64 Sieve	0.0-57.8	11.9 (14.7)	3.6 (3.2)	7.1 (9.9)	9.7 (12.4)	6.1 (10.0)	nd	nd
% of Sample Passed Through an 18/64 Sieve	0.0-84.0	4.5 (12.6)	0.3 (0.9)	1.1 (2.5)	0.4 (0.9)	0.6 (1.0)	nd	nd

*data not reported; nd = not determined due to test not being performed for 5 or 10 years.

in the Kasin cultivars (Table 37). The range and mean 1000 seed weight of chickpeas grown in 2023 were 185-570 g and 398 g, respectively (Table 36). The mean 1000 seed weight was significantly lower than the 5-year and 10-year mean values of 443 and 427 g, respectively. The Nash cultivar had the highest 1000 seed weight at 526 g while the Kasin cultivar had the lowest value at 278 g (Table 37).

Water hydration capacity of chickpeas ranged from 87 to 135%, with a mean of 109% (Table 36). The water hydration capacity of chickpeas from 2023 was essentially the same as the 5- and 10-year mean values. Only minor differences in water hydration capacities were observed among cultivars. The Marvel cultivar had the highest water hydration capacity (120%) while Sierra had the lowest (102%) (Table 37). In 2022, Sierra also had the lowest (102%) water hydration capacity.

The **unhydrated seed percentage** was 0% for all chickpeas. The 0% unhydrated seeds matched the 5- and 10-year mean values of 0 and 1%, respectively (Table 36). All the cultivars had 0% mean unhydrated seed values (Table 37). No issues were observed with the rehydration of the chickpea samples. The **swelling capacity** of chickpeas ranged from 81 to 174%, with a mean value of 133% (Table 36). The mean swelling capacity value of chickpea from 2023 was significantly lower than the previous years (2019-2021) and the 5-year mean of 136%. However, the mean swelling capacity of chickpeas in 2023 was higher than the swelling capacity of chickpeas from 2022. The Nash cultivar had the greatest mean swelling capacity (165%) while the Sierra cultivar had the lowest value (122%) among chickpeas (Table 37). The lower water hydration capacity for the Sierra cultivar may be the reason for lower swelling capacity.

Table 37. Mean physical properties of chickpea cultivars grown in the USA, 2023.

Cultivar	Test Weight (lb/Bu)	1000 Seed Wt (g)	Water Hydration Capacity (%)	Unhydrated Seeds (%)	Swelling Capacity (%)	Cooked Firmness (N/g)	% of Sample Retained on 22/64 Sieve	% of Sample Retained on 20/64 Sieve	% of Sample Retained on 18/64 Sieve	% of Sample Passed Through an 18/64 Sieve
CDC Frontier	60.9	342	108	0	131	19.7	32.7	49.3	16.3	1.6
CDC Orion	61.7	366	109	0	138	22.6	51.9	38.0	8.7	1.3
Dylan**	57.5	512	109	0	138	25.2	88.2	10.3	1.5	0.0
Kasin	63.8	278	114	0	133	22.1	1.3	22.6	54.0	22.1
Marvel	63.7	204	120	0	144	20.4	0.1	3.1	31.1	65.8
Nash**	58.9	526	109	0	165	22.7	85.2	10.6	3.0	1.2
Quinn**	60.2	465	115	0	128	18.0	83.9	12.5	2.3	1.3
Royal	58.7	480	118	0	129	20.6	79.4	17.1	3.0	0.5
Sawyer	61.8	390	109	0	145	18.5	46.7	44.1	8.5	0.8
Sierra	58.9	463	102	0	122	19.5	76.7	18.9	3.4	1.0
Unknown	61.7	358	108	0	141	20.5	54.1	31.4	10.9	3.6

**Value from only one sample of cultivar tested.

The **cooked firmness** of all chickpeas ranged from 13.4 to 27.8 N/g, with a mean value of 20.3 N/g (Table 36). The mean firmness value for chickpea in 2023 was lower than the 5-year mean value (21.3 N/g). This supports chickpea were slightly less firm after cooking compared to chickpea from previous years and that the chickpea cooking using a standard time produced chickpea with a tender structure. Among the cultivars, Quinn had the lowest cooked firmness (18.0 N/g) while and Dylan (25.2 N/g) cultivar was the firmest (Table 37).

Retention of chickpea on a series of sieves was used to determine chickpea size. The mean retentions of 53.8, 29.9, 11.9, and 4.5% on the 22/64-, 20/64-, 18/ 64- and passed through the 18/64-inch sieves were observed in the 2023 chickpeas, respectively (Table 36). The range of retention on the largest screen (22/64-inch sieve) was from 0.0 to 95.0%. The percentage of retention of chickpeas on the two largest screens (22/64 and 20/64-inch sieve) was approximately 83.7% in 2023 while retention values of 96, 92, 90 and 93% were observed for the chickpea harvested in 2022, 2021, 2020 and 2019, respectively. This data shows that smaller seed were evaluated in 2023.The highest percentage retention (88.2%) of the samples on the 22/64-inch sieve was observed for the Dylan cultivar while the lowest (0.1%) retention on the 22/64-inch sieve was observed in the Marvel cultivar (Table 37). The combination of Marvel and Kasin (1.3% retained on 22/64-inch sieve) contributed most to the lower seed retention on the 22/64-inch sieve in 2023.

Color quality was measured using L*, a*, and b* values and from these values a color difference was determined on chickpeas before and after soaking (Table 38). **Color quality** indicated that the lightness (i.e., L*) of the chickpeas from 2023 was less than chickpeas grown in 2020-2022 and the chickpea that made up the 10-year mean L* value (Table 38). In contrast, the L* value for chickpeas grown in 2023 was greater than the 5-year mean L* values meaning that the chickpeas from 2023 were lighter than the chickpeas that made up 5-year mean L* value. In 2023, the a* value of 6.14 was most similar to the a* value of chickpea from 2020. Furthermore, the a* value was substantially lower for the chickpea from 2023 compared to the 5- and 10-year a* values of 6.52 and 7.46, respectively. This indicates that the chickpea had less redness compared to the long-term averages. The b* value for chickpeas from 2023 indicated similar yellowness to the chickpea from 2021 and 2022, but less yellowness compared to chickpea samples that were used to determine the 5- and 10-year mean yellowness (i.e., b*) (Table

38). The color of the chickpeas changed after the soaking process. Soaked chickpeas became lighter as evidenced by the higher L* values (Table 38) compared to pre-soaked chickpeas. This same trend occurred in samples from previous years. The redness (i.e., a* value) did change slightly after soaking. Chickpeas from all years became yellower (i.e., increased b* value) after soaking. The color difference between the pre- and post-soaked chickpea from 2023 was most similar to the color difference for samples from 2020 but higher than in chickpea from 2022 and lower than in chickpea that were used in the determination of the 5-year mean b* value (Table 38).

Table 38. Color quality of Kabuli chickpeas grown in the USA before and after soaking, 2019-2023 plus 5- and 10-year mean values.

Color Scale*	Mean (SD) Color Values					
	Before Soaking				5-Year	10-Year
	2023	2022	2021	2020	Mean	Mean
L* (lightness)	59.21 (1.59)	60.57 (1.17)	61.33 (1.25)	60.47 (1.43)	58.30 (3.51)	61.07 (8.33)
a* (red-green)	6.14 (0.63)	6.01 (0.51)	6.31 (3.73)	6.07 (1.60)	6.52 (1.48)	7.46 (1.93)
b* (yellow-blue)	14.64 (1.27)	14.48 (0.67)	14.41 (2.07)	15.49 (1.37)	15.41 (3.93)	18.39 (5.23)
Color Scale*	**After Soaking**				**5-Year**	**10-Year**
	2023	**2022**	**2021**	**2020**	**Mean**	**Mean**
L* (lightness)	59.68 (1.13)	60.96 (1.12)	61.79 (0.68)	61.39 (0.72)	59.39 (2.74)	62.96 (10.11)
a* (red-green)	6.52 (0.48)	6.77 (0.46)	6.69 (0.52)	6.41 (1.71)	7.28 (2.36)	8.57 (2.76)
b* (yellow-blue)	25.24 (3.52)	24.40 (1.27)	24.81 (1.68)	25.78 (1.72)	25.38 (6.39)	30.91 (9.60)
Color Difference	10.80 (3.26)	9.85 (1.10)	11.23 (3.35)	10.47 (1.79)	12.58 (7.29)	nd

color scale L(lightness) axis – 0 is black and 100 is white; a *(red-green) axis – positive values are red, negative values are green, and zero is neutral; and b* (yellow-blue) axis – positive values are yellow, negative values are blue, and zero is neutral. nd = not determined due to test not being performed for 5 or 10 years. Color difference is the change in color after soaking.

Among cultivars, Nash had the highest L* value (60.55) while Quinn had the lowest (i.e., 54.36). The Dylan cultivar had the lowest a* value (4.76) among cultivars while Kasin had the highest (6.92). The highest yellowness value (i.e., b*) was observed in Kasin (Table 39). Visual observations support the color value differences as the Dylan cultivar appeared beige in color and less yellow than other cultivars. With the exception of a few cultivars, most underwent an increase in lightness during soaking, as evidenced by the higher L* value of the soaked samples. An increased yellowness (increased b* value) was observed for all cultivars. The greatest color difference was observed in the CDC Frontier cultivar (Table 39) while the Sierra cultivar had the least color change. The Sierra cultivar also had the least color change after soaking in 2021 and 2022. The change in color observed in the samples was likely due to the significant increase in yellowness (a change in b* values) during the soaking. The color change is supported by visual observations where the chickpea appeared more yellow after soaking.

Table 39. Mean color quality of chickpea cultivars grown in the USA, 2023.

	Mean Color Values**						
	Before Soaking			After Soaking			Color
Cultivar	L	a	b	L	a	b	Difference
CDC Frontier	59.53	6.38	14.93	60.23	6.66	27.88	13.07
CDC Orion	59.02	6.68	15.31	59.59	7.06	25.30	10.33
Dylan**	60.46	4.76	12.27	59.00	6.03	23.63	11.60
Kasin	57.97	6.92	16.62	61.17	6.61	27.56	11.42
Marvel	59.37	6.77	16.02	61.79	6.20	25.71	10.14
Nash**	60.55	5.93	14.51	58.80	6.76	24.80	10.51
Quinn**	54.36	5.62	11.85	57.65	6.55	23.39	12.21
Royal	57.78	5.91	13.14	58.24	6.88	24.50	11.50
Sawyer	59.15	6.35	15.35	59.86	6.19	25.02	9.75
Sierra	60.52	5.47	14.02	59.61	6.06	23.43	9.59
Unknown	59.18	6.24	14.80	59.46	6.78	24.69	10.02

*color scale: L (lightness) axis – 0 is black and 100 is white; a (red-green) axis – positive values are red, negative values are green, and zero is neutral; and b (yellow-blue) axis – positive values are yellow, negative values are blue, and zero is neutral. **Only one sample of cultivar tested.

Pasting properties (Tables 40-41)

A large variability in peak (71-206 RVU), hot paste (69-192 RVU) and cold paste (68-301 RVU) viscosities were observed in the 2023 chickpea crop. Peak, hot paste, and cold paste viscosities of chickpeas grown in 2023 were lower than the 5- and 10-year mean peak, hot paste, and cold paste viscosities (Table 40). The peak time was slightly longer for samples from 2023 compared to other crop years but was the same as the mean 10-year value. The pasting temperature was higher for the chickpeas from 2023 compared to chickpeas from other years and to the 5-year mean pasting temperature. Among chickpeas, Marvel had the lowest peak viscosity (103 RVU) while Royal (141 RVU) had the highest peak viscosity (Table 41). In 2022, Royal also had the highest peak viscosity (139 RVU). The Marvel and Dylan cultivars had the lowest and highest hot paste viscosities, respectively. These cultivars also had the lowest and highest cold paste viscosities (Table 41). Pasting temperature was lowest (76.2 °C) and highest (79.8 °C) for Sierra and Marvel cultivars, respectively. The RVA gel firmness ranged from 55 to 269 g with a mean of 159 g (Table 40). The mean gel firmness was substantially less than the gel firmness of chickpeas from 2022. The Dylan cultivar had the firmest (i.e., highest value) RVA gel firmness while Marvel produced a gel with the least firmness (Table 41). These outcomes match the cold paste viscosities where higher cold paste viscosity also results in higher gel firmness.

Table 40. Starch characteristics of Kabuli chickpeas grown in the USA, 2019-2023 plus 5- and 10 year mean values.

Starch Characteristic	Year							
	2023		2022	2021	2020	2019	5-year	10-year
	Range	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Peak Viscosity (RVU)	71-206	122 (20)	125 (14)	129 (20)	136 (16)	136 (18)	131 (5)	138 (15)
Hot Paste Viscosity (RVU)	69-192	116 (19)	121 (12)	123 (18)	128 (13)	131 (16)	126 (4)	131 (10)
Breakdown (RVU)	12785	6 (5)	4 (4)	10 (1)	7 (5)	5 (4)	6 (2)	7 (6)
Cold Paste Viscosity (RVU	68-301	154 (33)	189 (28)	200 (53)	186 (23)	198 (30)	192 (6)	206 (32)
Setback (RVU)	0-109	37 (16)	68 (17)	77 (36)	58 (15)	68 (18)	67 (7)	70 (29)
Peak Time (Minute)	5.10-7.00	6.59 (0.50)	6.53 (0.58)	6.47 (0.63)	6.12 (0.56)	6.33 (0.57)	6.30 (0.21)	6.58 (1.18)
Pasting Temperature (°C)	52.0-81.4	78.2 (3.4)	77.1 (1.4)	76.9 (1.2)	78.0 (1.4)	75.6 (1.6)	76.7 (1)	nd
RVA Gel Firmness (g)	55-269	159 (37)	272 (54)	*	*	*	nd	nd

*not previously measured; nd = not determined due to test not being performed for 5 or 10 years.

Table 41. Mean starch characteristics of chickpea cultivars grown in the USA, 2023.

Cultivar	Peak Viscosity (RVU)	Hot Paste Viscosity (RVU)	Breakdown (RVU)	Cold Paste Viscosity (RVU)	Setback (RVU)	Peak Time (Min)	Pasting Temperature (°C)	RVA Gel Firmness (g)
CDC Frontier	125	120	5	155	35	6.68	79.2	149
CDC Orion	116	112	4	140	28	6.62	78.9	134
Dylan**	136	133	3	186	53	6.07	76.7	180
Kasin	115	111	4	141	31	6.91	79.4	128
Marvel	103	99	4	119	20	6.87	79.8	120
Nash**	120	115	6	159	44	7.00	78.5	154
Quinn**	122	119	3	164	45	6.80	77.9	157
Royal	141	129	12	168	40	5.82	78.0	178
Sawyer	119	112	7	149	36	6.54	78.4	173
Sierra	121	117	4	164	48	6.85	76.2	179
Unknown	115	109	7	134	25	6.66	79.4	141

**Value from only one sample of cultivar tested.

Functional properties (Tables 42-43)

Functionality property evaluation was new in 2022. Thus, only 2 years of data exists on emulsion activity and stability, foaming capacity and stability, water holding capacity and oil holding capacity. The emulsion activity and stability for all chickpea samples ranged from 52-58% and 50-59% (Table 42). However, no differences in emulsion activity and stability were observed based on cultivar (Table 43). In contrast to emulsion activity, foaming capacity varied to a greater extent (100-257%). Differences in foaming capacity among different cultivars of chickpeas were observed (Table 43). Nash had a mean foaming capacity of approximately 207%. In contrast, the Quinn had the lowest foaming capacity at 133%. Quinn also had a slightly lower foam stability than other cultivars except Kasin and Marvel. Higher mean water holding capacity was observed in chickpeas from 2023 compared to 2022. Quinn and CDC Orion had the highest water holding capacities compared to other cultivars while Dylan and Royal had the lowest water holding capacities. Minimal differences in the oil holding capacities were observed in the chickpeas from 2023. However, CDC Frontier, Royal, and Sierra had slightly higher oil holding capacities.

Table 42. Functional properties of Kabuli chickpeas grown in the USA, 2022-2023.

Starch Characteristic	Year		
	2023		2022
	Range	Mean (SD)	Mean (SD)
Emulsion Activity (%)	52-58	55 (1)	57 (1)
Emulsion Stability (%)	50-59	56 (1)	58 (1)
Foaming Capacity (%)	100-257	169 (29)	164 (20)
Foam Stability (%)	64-100	86 (8)	85 (5)
Water Holding Capacity (g/g)	0.5-1.8	1.1 (0.2)	1.01 (0.11)
Oil Holding Capacity (g/g)	0.09-0.39	0.20 (0.07)	0.25 (0.09)

Table 43. Functional properties of chickpea cultivars grown in the USA, 2023.

Cultivar	Emulsion Activity (%)	Emulsion Stability (%)	Foaming Capacity (%)	Foam Stability (%)	Water Holding Capacity (g/g)	Oil Holding Capacity (g/g)
CDC Frontier	56	56	173	87	1.2	0.23
CDC Orion	55	55	183	84	1.3	0.16
Dylan**	56	55	177	91	1.0	0.10
Kasin	56	56	180	82	1.2	0.13
Marvel	55	54	190	82	1.2	0.15
Nash**	57	56	207	86	1.2	0.16
Quinn**	56	57	133	83	1.3	0.17
Royal	55	56	168	87	1.0	0.22
Sawyer	55	55	158	84	1.2	0.20
Sierra	56	56	161	89	1.1	0.22
Unknown	56	54	170	89	1.2	0.15

**Value from only one sample of cultivar tested.

Canning Quality Results

Canning quality was completed only on pea and chickpea. The quality evaluation includes hydration capacity, swelling capacity, canned firmness, and color evaluation. Hydration capacity and swelling capacity were completed following the soak test method. The only difference was that the hydration and swelling capacity was measured on a canned pea or chickpea.

Peas (Tables 44-46)

The mean **water hydration capacity** of canned peas was 210% for all peas (Table 44). This value is higher than the water hydration capacity of peas from the most recent crop years except 2019 and 2022. The water hydration capacity of the pea from 2023 is similar to the 5-year mean water hydration value. Water hydration capacities ranged from 133 to 246% for all peas in 2023. A difference in water hydration capacity between the green (206%), yellow (206%) and winter (236%) classes were observed (Table 44). Furthermore, Winter pea (248%) had the highest water hydration capacities among market classes (Table 44). Overall, the data for the green and yellow peas indicates more water uptake of the peas from 2023 compared to previous years except 2020 and 2022. In winter peas, only peas from 2022 had higher water uptake than the peas from 2023. In green peas, mean water hydration capacity ranged from 168% (Banner) to 249% (Ariel) (Table 45). In yellow cultivars, Puns 0667 had the highest (271%) mean water hydration capacities while the CDC Leroy cultivar had the lowest (133%) value (Table 45). The winter pea cultivar Keystone had the highest water hydration capacity (271%) compared to all peas. The results of the soak test did not directly translate into equivalent results as in the canning water hydration in the context of an order for the cultivars.

Table 44. Mean physical parameters of canned dry pea grown in 2019-2023 plus the 5-year mean value.

Physical Parameter	2023 Range	2023 Mean (SD)	2022 Mean (SD)	2021 Mean (SD)	2020 Mean (SD)	2019 Mean (SD)	5-year Mean (SD)
All Pea Samples							
Water Hydration Capacity (%)	133-277	210 (37)	231 (24)	143 (28)	199 (30)	260 (46)	209 (43)
Swelling Capacity (%)	155-246	200 (24)	165 (18)	181 (12)	205 (19)	204 (24)	194 (12)
Canned Firmness (N/g)	3.2-19.7	9.1 (5.2)	5.8 (2.0)	17.8 (7.6)	7.3 (3.0)	5.9 (2.3)	8.3 (5.4)
Green Pea Samples							
Water Hydration Capacity (%)	158-267	206 (27)	221 (20)	137 (21)	198 (32)	254 (45)	201 (43)
Swelling Capacity (%)	157-224	189 (16)	156 (14)	180 (11)	204 (20)	200 (20)	189 (21)
Canned Firmness (N/g)	3.2-19.7	9.2 (3.7)	6.6 (1.0)	19.0 (6.7)	7.2 (3.1)	6.35 (2.31)	8.9 (5.7)
Yellow Pea Samples							
Water Hydration Capacity (%)	133-277	206 (42)	219 (30)	162 (29)	199 (28)	265 (46)	214 (38)
Swelling Capacity (%)	155-243	210 (25)	152 (17)	182 (14)	206 (20)	206 (25)	192 (26)
Canned Firmness (N/g)	4.3-15.3	9.7 (6.8)	7.4 (1.9)	12.6 (6.7)	7.4 (3.0)	5.73 (2.21)	7.5 (3.1)
Winter Pea Samples							
Water Hydration Capacity (%)	145-275	236 (46)	248 (7)	123 (8)	217 (23)	214 (41)	nd
Swelling Capacity (%)	173-246	210 (30)	181 (5)	180 (12)	211 (6)	204 (16)	nd
Canned Firmness (N/g)	3.7-15.5	7.1 (4.3)	3.9 (0.4)	23.7 (3.6)	7.3 (2.4)	7.39 (4.28)	nd

nd= not determied since canning has not been determined on winter market class for 5 years.

Table 45. Mean physical and color parameters of canned dry pea cultivars grown in 2023.

Market Class	Cultivar	Hydration Capacity (%)	Swelling Capacity (%)	Canned Firmness (N/g)	Before Soaking L*	Before Soaking a*	Before Soaking b*	After Soaking L*	After Soaking a*	After Soaking b*	Color Difference
					Mean Color Values*						
Green	Aragon**	212	189	6.7	57.72	-2.53	9.55	49.21	-0.21	18.26	12.44
	Arcadia	193	195	13.9	59.57	-0.75	9.20	50.02	0.72	16.65	12.38
	Ariel**	249	169	8.6	58.58	-2.13	8.94	51.14	-0.45	18.27	12.06
	Banner	168	165	12.8	54.33	-1.95	8.91	46.84	0.16	14.29	9.57
	CDC Forest**	226	189	6.4	63.00	5.15	14.85	55.16	6.89	25.65	13.48
	Compass	197	181	8.6	55.52	-1.70	7.91	49.79	-0.84	16.37	10.51
	Ginny 2	192	197	9.7	58.37	-1.71	9.00	48.00	0.60	17.04	13.34
	Hampton	224	195	5.3	58.60	-2.06	9.43	48.52	-0.27	17.36	13.08
	Passion	191	184	12.0	58.09	-1.88	9.35	49.78	-0.58	16.74	11.27
	Striker	227	206	7.8	58.92	-0.04	9.46	51.44	2.41	19.02	12.54
Yellow	CDC Leroy**	133	155	4.5	62.65	5.06	15.34	53.64	7.56	23.64	12.50
	CDC Meadow	218	228	7.2	63.04	4.42	16.13	55.76	7.04	26.15	12.86
	Hyline**	183	193	9.0	64.82	5.07	14.69	53.45	6.22	22.27	13.73
	Montech**	177	197	7.5	64.60	5.35	15.36	56.13	5.45	24.24	12.30
	Orchestra**	181	197	8.8	64.56	5.00	14.51	54.11	6.90	23.03	13.64
	Puns 0667**	271	233	4.3	59.96	4.92	14.14	57.68	5.22	25.36	11.48
	Salamanca	231	205	7.6	63.89	5.08	14.74	54.91	6.51	23.52	13.11
	Spider**	232	232	5.8	62.32	4.63	14.81	56.11	6.49	25.69	12.71
	Thunderbird**	165	190	8.2	62.20	4.44	14.50	53.70	8.07	24.41	13.56
	Treasure**	228	243	7.2	65.02	4.81	15.17	54.78	6.79	24.37	13.91
	Unknown	206	212	9.9	62.83	5.13	14.88	54.34	6.26	24.15	13.03
Winter Green	Keystone**	275	246	3.7	56.76	0.19	9.06	51.78	-0.08	17.78	10.07
	Vail	264	210	4.4	51.80	-1.30	8.12	49.09	-0.84	18.55	10.86
Winter Yellow	Blaze	215	209	9.0	59.73	3.21	15.01	54.91	4.96	24.55	11.03
	Goldenwood**	204	173	10.2	59.87	4.56	12.89	54.85	5.58	21.58	10.10

*color scale: L (lightness) axis – 0 is black and 100 is white; a (red-green) axis – positive values are red, negative values are green, and zero is neutral; and b (yellow-blue) axis – positive values are yellow, negative values are blue, and zero is neutral. **Only one sample of cultivar tested.

The **swelling capacity** is the amount of swelling that occurred during rehydration of the dry pea and the canning operation. The swelling capacity of all peas ranged from 155 to 246%, with a mean value of 200% (Table 44). These values were slightly lower than the swelling capacity of peas from the 2019-2020 crop years, but slightly higher than the 5-year mean value. The yellow and winter peas had the same mean swelling capacities (210%) while green peas had lower (189%) mean swelling capacity. The green pea cultivars Striker and Banner had the highest (206%) and lowest (165%) mean swelling capacities, respectively. In yellow cultivars, Treasure had the highest (243%) mean swelling capacity while the CDC Leroy cultivar had the lowest swelling capacity at 155% (Table 45). The winter pea cultivars Keystone and Goldenwood had the highest (246%) and lowest (173%) mean swelling capacities, respectively.

As expected, the **canned firmness** values of peas were significantly lower than the cooked firmness values of soaked peas in 2023. For comparison, the mean cooked firmness for all peas from 2023 was 22.6 N/g (Table 7) while for canned pea, in 2023, the mean firmness value was 9.1 N/g (Table 44). This observation is typical of what is expected and demonstrates the typical behavior of peas from 2023. The mean canned firmness of the peas from 2023 most closely matched the mean canned firmness of peas from 2020. The mean canned firmness of peas from 2023 was slightly more than that of the 5-year mean canned firmness value (Table 44). In general, winter peas had the lowest (7.1 N/g) and yellow peas the highest (9.7 N/g) canned firmness. For both the green and yellow peas, the mean firmness values were greater than the values for the 5-year mean suggesting slightly firmer peas, but significantly less firm than the peas from 2021. The Hampton cultivar was the least firm (5.3 N/g) among the green peas while Arcadia (13.9 N/g) was the firmest (Table 45). Puns 0667 had the lowest (4.3 N/g) firmness while Hyline had the greatest (9.0 N/g) firmness among yellow cultivars. In winter peas, Keystone had the least firmness (3.7 N/g) while Goldenwood had the highest firmness (10.2 N/g).

Table 46. Mean color characteristics of canned dry pea grown in 2019-2023 plus the 5-year mean value.

	Mean (SD) Color Values*						
	Before Canning			After Canning			
Sample**	L	a	b	L	a	b	Color Difference
Green Pea Samples							
2023	55.85 (3.12)	-2.01 (0.18)	10.23 (2.57)	48.21 (2.65)	0.37 (1.19)	19.20 (7.03)	12.85 (3.20)
2022	58.25 (2.03)	-2.08 (0.52)	10.11 (0.65)	50.05 (1.41)	0.13 (1.05)	18.92 (1.43)	12.51 (1.33)
2021	57.33 (2.35)	-2.30 (1.01)	10.45 (0.74)	48.03 (1.38)	0.32 (0.41)	14.50 (1.26)	10.67 (1.67)
2020	58.60 (2.46)	-1.87 (0.74)	9.46 (0.78)	51.62 (1.55)	-0.35 (1.37)	19.59 (2.06)	12.88 (1.65)
2019	53.40 (1.59)	-1.88 (0.73)	7.00 (0.60)	45.33 (2.02)	-0.63 (0.58)	12.41 (1.30)	10.04 (1.54)
5-Year Mean	54.77 (3.02)	-1.85 (0.37)	11.24 (3.37)	47.44 (2.54)	0.83 (1.48)	21.25 (8.31)	13.67 (3.59)
Yellow Pea Samples							
2023	61.76 (2.81)	5.24 (1.03)	14.79 (2.17)	55.07 (2.35)	5.34 (1.41)	23.44 (5.45)	11.87 (1.74)
2022	63.65 (1.20)	4.91 (0.90)	15.62 (0.43)	55.03 (2.62)	4.97 (1.42)	22.97 (3.03)	12.10 (1.07)
2021	64.29 (1.26)	5.30 (0.39)	15.04 (0.78)	55.91 (1.54)	7.04 (0.98)	23.14 (1.44)	11.95 (1.09)
2020	63.47 (2.66)	4.99 (0.69)	14.57 (1.25)	56.46 (4.86)	4.14 (1.43)	24.49 (2.24)	13.08 (4.63)
2019	58.63 (1.72)	4.10 (0.54)	11.39 (0.71)	51.06 (1.58)	3.95 (0.81)	15.65 (1.29)	8.94 (1.98)
5-Year Mean	60.73 (2.89)	5.60 (1.19)	15.72 (3.32)	55.01 (2.36)	5.59 (1.44)	24.78 (6.08)	11.66 (1.77)
Green Winter Pea Samples#							
2023	53.45 (3.00)	-0.80 (0.96)	8.43 (0.64)	49.98 (1.66)	-0.59 (0.44)	18.29 (1.11)	10.59 (0.87)
2022	nd	nd	nd	nd	nd	nd	nd
2021	53.88 (0.34)	-2.54 (0.23)	8.49 (0.51)	45.06 (1.12)	0.24 (0.23)	12.99 (0.62)	10.35 (1.39)
2020	55.31 (1.11)	-1.84 (0.61)	8.93 (0.67)	51.10 (0.31)	-2.89 (0.19)	21.77 (1.30)	13.56 (0.92)
2019	49.36 (0.53)	-2.25 (0.04)	6.09 (0.03)	44.52 (0.41)	-0.88 (0.53)	11.57 (1.12)	7.47 (0.63)
Yellow Winter Pea Samples#							
2023	59.77 (0.31)	3.55 (0.77)	14.48 (1.06)	54.90 (1.05)	5.12 (0.35)	23.81 (2.03)	10.80 (0.87)
2022	60.28 (0.58)	2.01 (0.57)	13.36 (0.44)	56.32 (0.53)	2.81 (0.67)	24.32 (1.44)	11.77 (1.33)
2021	59.71 (3.01)	1.96 (1.87)	13.91 (0.88)	51.37 (0.25)	3.43 (0.81)	19.58 (0.16)	10.67 (1.43)
2020	60.29 (0.83)	2.52 (0.32)	14.28 (0.49)	57.42 (1.49)	3.82 (0.28)	26.78 (3.20)	13.04 (2.95)
2019	nd	nd	nd	nd	nd	nd	nd

color scale: L (lightness) axis – 0 is black and 100 is white; a* (red-green) axis – positive values are red, negative values are green, and zero is neutral; and b* (yellow-blue) axis – positive values are yellow, negative values are blue, and zero is neutral. **Includes all pea samples or separated into market class. #Canning quality not determined on winter pea prior to 2019. nd= no sample evaluated within the green or yellow winter market class.

The color of the dry pea changed after the canning process. The color difference fell between 9.57 and 13.56 for all peas with winter having the lowest color difference values. The lower color difference of yellow winter pea in 2023 suggests that the winter pea color is impacted less by processing compared to green and yellow pea. Except for the 2019 and 2021 production years, the color difference between the dry and canned peas was less than previous crop years (Table 46). The lightness decreased during canning for all market classes. In the soak test, only the green cultivars darkened upon soaking (Table 10). The green peas tended to become less green and more yellow during canning as evidenced by the increasing a* and b* values, respectively. The yellow peas and yellow winter peas became darker and more yellow after canning. The greatest color difference was observed in the CDC Forest (green) and Treasure (yellow) cultivars after canning (Table 45) while the Banner (green) and Puns 0667 (yellow) cultivars had the lowest color difference. Of the pea classes, the yellow winter pes from 2023 most aligned with winter peas from 2021. No other class had two years of peas with similar color data.

Chickpeas (Tables 47-48)

The mean **water hydration capacity** of canned chickpea was 198% with a range from 160 to 258%. The mean water hydration value in 2023 was significantly higher comparable to the canned chickpeas from previous years (Table 47). The mean water hydration capacity of canned chickpea from 2023 was 50 percentage points higher than that observed for the 5-year mean (148%). The Marvel cultivar had the highest water hydration capacity at 230% while Sierra had the lowest at 188% (Table 48). The **swelling capacity** is the amount of swelling that occurred during rehydration of the dry chickpea and the canning operation. The swelling capacity of all chickpeas ranged from 151 to 211%, with a mean value of 124%. The Sierra cultivar had the lowest swelling capacity at 172% while Marvel had the highest at 202% (Table 48).

Table 47. Mean physical and color parameters of canned chickpea grown in 2019-2023 plus the 5-year mean value.

Year	Hydration Capacity (%)	Swelling Capacity (%)	Canned Firmness (N/g)	Mean (SD) Color Values* Before Soaking L	a	b	After Soaking L	a	b	Color Difference
2023	198 (15)	188 (16)	8.2 (2.1)	59.12 (1.59)	6.12 (0.60)	14.52 (1.18)	53.63 (1.08)	6.18 (0.61)	18.25 (1.15)	6.99 (1.39)
2022	163 (10)	124 (10)	6.6 (0.6)	61.36 (1.05)	6.16 (0.54)	14.77 (0.68)	53.88 (1.01)	5.53 (0.45)	17.68 (1.05)	8.24 (1.17)
2021	128 (9)	163 (13)	14.8 (1.4)	61.38 (1.11)	5.85 (0.56)	14.35 (0.69)	51.79 (0.80)	6.42 (0.53)	15.66 (0.90)	9.81 (1.17)
2020	162 (9)	177 (12)	8.0 (0.9)	60.34 (1.39)	5.89 (1.76)	15.66 (1.40)	53.48 (1.99)	5.00 (1.54)	19.19 (2.20)	8.39 (2.02)
2019	164 (12)	192 (11)	6.7 (0.9)	55.99 (1.64)	5.27 (0.63)	10.88 (0.82)	46.84 (1.03)	4.50 (0.72)	11.66 (1.08)	9.48 (1.84)
5-Year Mean	148 (20)	166 (26)	9.2 (3.4)	56.50 (4.87)	6.45 (1.50)	15.48 (3.94)	50.68 (3.35)	6.01 (1.62)	18.20 (5.58)	9.04 (0.69)
2023 (Data Range)	160-258	151-221	5.1-14.0	54.35-62.38	4.76-7.50	11.85-17.54	50.53-56.04	4.92-7.49	15.26-20.92	3.96-10.29

*color scale: L (lightness) axis – 0 is black and 100 is white; a (red-green) axis – positive values are red, negative values are green, and zero is neutral; and b (yellow-blue) axis – positive values are yellow, negative values are blue, and zero is neutral.

Table 48. Mean physical and color parameters of canned dry chickpea cultivars grown in 2023.

Cultivar	Hydration Capacity (%)	Swelling Capacity (%)	Canned Firmness (N/g)	Mean Color Values* Before Soaking L	a	b	After Soaking L	a	b	Color Difference
CDC Frontier	202	185	7.7	59.47	6.35	14.85	53.90	6.56	18.54	6.97
CDC Orion	200	199	10.3	58.39	6.54	14.89	53.46	6.24	18.71	6.43
Dylan**	191	179	7.1	60.46	4.76	12.27	54.27	6.12	18.98	9.56
Kasin	200	194	6.0	57.97	6.92	16.62	54.29	5.85	18.59	4.51
Marvel	230	202	8.8	59.48	6.81	15.99	55.88	6.75	19.33	5.07
Nash**	213	181	6.4	60.55	5.93	14.51	52.46	5.54	17.42	8.65
Quinn**	198	199	8.2	54.36	5.62	11.85	52.99	7.18	18.92	7.37
Royal	193	185	8.1	57.78	5.91	13.14	52.80	6.06	17.49	6.84
Sawyer	207	201	8.6	59.18	6.30	15.26	54.15	6.48	19.10	6.55
Sierra	188	172	7.5	60.55	5.48	13.90	53.50	5.86	17.55	8.31
Unknown	199	194	10.9	58.84	6.27	14.55	52.96	5.92	18.02	7.37

*color scale: L (lightness) axis – 0 is black and 100 is white; a (red-green) axis – positive values are red, negative values are green, and zero is neutral; and b (yellow-blue) axis – positive values are yellow, negative values are blue, and zero is neutral. **Only one sample of cultivar tested.

The **canned firmness** values of chickpeas were lower than the cooked firmness values of soaked chickpeas. The mean canned firmness value of all chickpeas was 8.2 N/g (Table 47). In comparison, the mean cooked firmness for all chickpeas was 20.3 N/g (Table 36). As expected, the canned chickpeas were less firm than the cooked chickpeas. The mean firmness value for canned chickpeas in 2023 most matched the canned chickpeas from 2020. The firmness of chickpea in 2023 was slightly less than the chickpeas that made up the 5-year mean value.

Canned Kasin chickpeas had the least firmness (6 N/g) while the CDC Orion chickpeas were the firmest (10.3 N/g) (Table 48). The color of the chickpeas changed after the canning process. The color difference fell between 3.96 and 10.29, with a mean value of 6.99 for all chickpeas (Table 47). The color difference for the canned chickpea in 2023 were significantly lower comparable to the canned chickpeas from the other crop year. This supports less color change for the samples after canning compared to previous years. A higher color difference was observed in soaked (10.80) chickpeas compared to canned (6.99) chickpeas. The L* or lightness decreased during canning (Table 47), which agrees with canned chickpeas from previous years. In contrast, the L* values of chickpeas increased in the soak test. The yellowness increased in canned chickpea and again agrees with the trend of increasing yellowness after canning as observed in prior years. Unlike prior years, the redness value (a*) increased in the canned chickpea. The highest color difference after canning was observed in the Dylan cultivar (9.56) while Kasin had the least (4.51) color change (Table 48).

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