2021

U.S. Pulse Quality Survey

Northern Pulse Growers Association

USA Dry Pea & Lentil Council

Contents

2021 Overview and Author's Comments

Summary Points

1. The 2021 pulse quality report represents the 14th variation of a pulse quality evaluation started by the Northern Crops Institute in 2008. 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 approximately 121 samples received from major US pulse growing regions were evaluated. The drought had a significant impact on sample collection in 2021.
3. Significant impacts on protein (higher percentage) and starch (lower percentage) were observed predominantly in peas.
4. Pea had significantly lower 1000 seed weights in 2021 while 1000 seed weights for lentil and chickpea were near long-term mean values.
5. Pea and lentil had lower water hydration and swelling capacities compared to long-term mean values.
6. Pea and lentil had lower pasting viscosities compared to long-term mean values which indicates thinner pastes resulted in 2021.
7. Overall, the physical properties of the chickpea were not as affected by the growing conditions compared to peas and lentils.
8. Faba bean quality on two samples was reported for the second time in the survey history.

This report provides a summary of the 2021 pulse crop quality for dry pea, lentil and chickpea grown commercially in the USA. In 2021, a total of 121 pulse samples were collected from the major US pulse growing regions. The seeds evaluated included 38 dry pea, 28 lentil, 2 faba beans, and 55 chickpea samples, which were acquired from pulses growers and industry representatives in pulse growing areas in Idaho, Montana, North Dakota, South Dakota, and Washington.

According to the USDA National Agricultural Statistics Service and the U.S. Dry Pea and Lentil Council, pulse harvested acres and estimated total production for 2021 was 1.73 million and approximately 700 thousand MT, respectively. Pulse acres in 2021 was higher compared to the 2020 harvest but lower than acres harvested in 2017-2019. Although more acres were harvested in 2021, the yield was approximately half per acre resulting in the lower production numbers. Unlike pea, lentil and chickpea harvested acres in 2021 was up compared to 2020. However, like pea, the production was approximately half that of 2020 for lentil and chickpea. A full breakdown of 2021 production can be found in the 2021 USDA Production / Stock Report (McGreevy, U.S. Dry Pea & Lentil Council).

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.

Results from the proximate (i.e., moisture, protein, etc.) composition analyses indicates that results aligned most closes with the 2018 crop year for dry pea, the 2018 and 2019 crop year for lentil and the 2017 crop year for chickpea. Faba bean also was evaluated in 2021. The last faba bean evaluated was in 2016. The results indicated that the brown faba bean tested in 2021 matched closely the results from the faba bean sample evaluated in 2016.

In general, pea, lentil, and chickpea from 2021 had the same or lower moisture contents compared pulses from previous crop years. All pulses had moisture contents lower than the 5-year mean moisture values. However, the moisture contents of the pulses from 2021 tended to match the 10-year mean moisture contents of their respective pulse crop. This suggests that the long-term moisture is a good guide to predicting moisture content of a pulse. In contrast, the total starch contents of all three pulses were significantly lower in 2021 compared to the 10-year mean starch content. However, the 5-year mean moisture value was a better predictor since the values from 2021 match the 5-year mean moisture value compared to the 10-year mean. The total starch percentages in lentils from 2021 was comparable to the lentils harvested in 2019 while total starch in peas and chickpeas grown in 2021 had comparable starch contents to peas and chickpea from 2018 and 2020, respectively. The mean protein percentage in peas from 2021 was higher than recent years, including the 5- and 10-year mean protein contents. Protein content from green peas most closely matched those from the 2020 harvest year. In contrast, the yellow peas had significantly higher protein content than yellow peas from other harvest years. Lentils from 2021 had protein contents similar to lentils from 2018 and 2020. Protein content in chickpea matched the 5-year mean value but was lower than the 10-year mean by only 0.3 percentage points. 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 ranges reported in the literature. The mean fat contents of peas and lentils from 2021 were lower than their respective crops from previous years. In contrast, the mean fat content of chickpeas from 2021 match the mean values of chickpeas from 2017 and 2020.

The physical parameters such as water hydration capacity, test weight, and color analysis of the 2021 had varying result compared to previous pulse crops. Overall, the test weight of dry peas and lentils were higher than their 5- and 10-year mean test weights while chickpea mean test weight in 2021 match the 5- and 10-year mean test weight. The most significant change in physical parameter in 2021 was the 1000 seed weight of peas. The 1000 seed weight was approximately 20 g less in 2021 compared to the 5- and 10-year mean 1000 seed weight. In contrast, lentils and chickpeas had 1000 seed weight that were either comparable or higher than the 5- and 10-year mean values. The water hydration capacities in 2021 were lower than the 5- and 10-year mean for lentil but comparable to the 5-year mean for pea and chickpea. Swelling capacity followed the same trend where the swelling capacity of lentils from 2021 were lower than the 5-year mean values and pea and chickpea were essentially the same as their respective 5-year mean swelling capacities. This indicates that pea and chickpea from 2021 tended to swell more than chickpea from previous years while lentils did not swell to the same extent as lentils from previous harvest years. A size distribution analysis of chickpea indicated a larger seed size for chickpea from 2021. The Pegasus chickpea cultivars had the highest percentage (96.6%) of seeds retained on a 22/64-inch sieve in 2021. One significant observation in the size analysis was that the Nash cultivar had a low (43.2%) percentage of seeds retained a 22/64-inch sieve in 2021 compared to the 85% in 2020. The impact of the drought likely contributed to the different seed size in 2021.

The color of the peas in 2021 were lighter than peas from other harvest years except 2020. The lighter color was supported by higher lightness (L*) values. The color difference values of dry peas vs. soaked peas from 2021 were generally lower than 5-year mean color difference value for both green and yellow peas. The color tended to be lighter for all lentils regardless of lentil color. This might be the result of the samples having less greenness values (a*) compared to previous years. The 2021 chickpea crop had slightly higher lightness values compared to previous crop years but had L* values comparable to the 10-year mean L* value. However, the yellowness values (b* value) of chickpea from 2021 were significantly lower than 5- and 10-year mean yellowness value. Overall, the color difference between dry and soaked chickpea was lower than the 5-year mean value.

The starch pasting properties for the 2021 pea and lentil were the most significantly different from previous years, so much so that there is no comparison to other years. The peak. Hot and cold paste viscosities were all significantly lower than peas and lentils from previous years. For example, the mean cold paste viscosity for peas was 204 RVU compared to the 5- and 10-year mean cold paste viscosity of 233 and 244, respectively. Similar variability was observed in the lentil sample. The paste that resulted from the pea and lentil flours was less viscous than the paste from the flours from other crop years. The cultivar evaluation showed that the Scotch cultivar for peas and the CDC Richlea and CDC Maxim-CL lentils had significantly lower paste viscosities. In contrast, chickpea from 2021 had pasting properties similar to the 5-and 10-year mean pasting properties. Overall, the physical properties of the chickpea were not as affected by the growing conditions compared to peas and lentils.

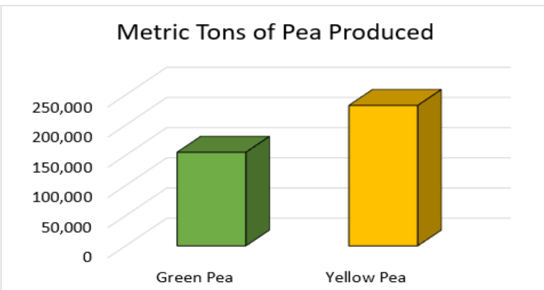
The canning evaluation was completed for a fifth time since the survey inception. Overall, the canning quality of pea from 2021 were significantly different from the previous canning evaluation. The canning data mirrored some of the physical data for the peas. Water hydration capacity and swelling capacity of the canned pea in 2021 were significantly lower than peas from 2017-2020. In contrast, canning firmness was significantly higher (2 to 3 times firmer) in 2021 compared to peas from other harvest years. Chickpea from 2021 had hydration capacity and swelling capacity similar to canned chickpea from 2017 and 2018. The mean canned firmness of chickpea from 2021 was 4.4 to 8.1 N/g higher than the mean canning firmness of chickpea from other harvest years.

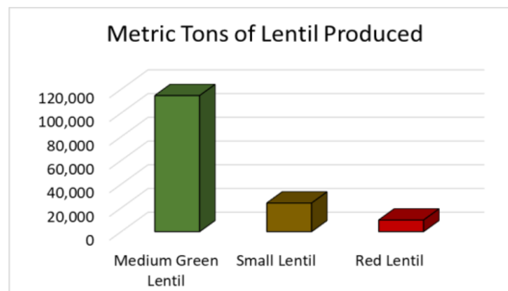
The focus of the pulse program is the quality evaluation and utilization of pulses as food and food ingredients. The mission of the Pulse Quality Program is to provide industry, academic and government personnel with readily accessible data on pulse quality and to provide science-based evidence for the utilization of pulses as whole food and as ingredients in food products. The data provided has been reported for a number of years. I welcome any thoughts, comment, 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,
Clifford Hall, Ph.D.
clifford.hall@sdstate.edu

Pulse Production

Northern Plains region and Pacific Northwest are the largest pulse producing area within the USA. US pulse harvested acreage in 2021 was 1,734,000 (Table 1), which was approximately 50 thousand more acres than in 2020 but 150 thousand less acres than in 2019. Total US pulse production (Metric Tons (MT) in 2021 is estimated to be 668,466 which is down significantly from the 1,357,838 produced in 2020. Pulse production was its lowest among the 2017-2021 crop years. The conditions affecting the pulse growing regions likely contributed to the lower production compared to the previous crop years. The USDPL council and UDSA estimated that the dry pea acreage was 834,000, which was down from the 919,000 in 2020 (Table 1). Pea production (387,780 MT) was less than the previous production of 941,571 MT in 2020 (Table1). Approximately 70 thousand MT more of yellow pea was produced compared to green peas. Lentil acreage was 549,000 in 2021 and is slightly higher than the 510,000 and 431,000 from 2020 and 2019, respectively (Table 1). Lentil production in 2021 was 150,912 MT. This was lower than the 230,881 and 273,723 MT in 2020 and 2019, respectively. Green lentils made up the majority of the lentil production. Nearly 90 thousand MT more green lentils were produced than brown and red lentils. Chickpea harvested acres in 2021 (351,000) was greater than the harvested acres (250,800) in 2020. Production was estimated at 129,774 MT, which is lower than the 250,800 MT in 2020. The lower production of the pulses supports decrease in yields per acres. The drought experience in the growing region had a significant and primary role in the low production of the pulse crops. The yield for dry pea was 1025 lbs./acre in 2021, which is down from 1,953 lbs./acre in 2020. Lentil yield (606 lbs./acre) were cut in half compared to 2020 yields (1,338 lbs./acre). Prior yields included 1,250, 1,171 and 732 lbs./acre yields from 2019, 2018 and 2017, respectively. Like peas and lentils, chickpea yield (815 lbs./acre was half of the 1630 lbs./acre in 2020 and lower than the 1,544, 1511 and 1,155 lbs./acre in 2019, 2018 and 2017, respectively. The large chickpeas accounted for nearly 110 thousand MT more than small chickpea. Overall, the acres harvested were equivalent to that of 2020; however, the lack of moisture during the growing season significantly impact production and demonstrates the importance in the production of pulses.





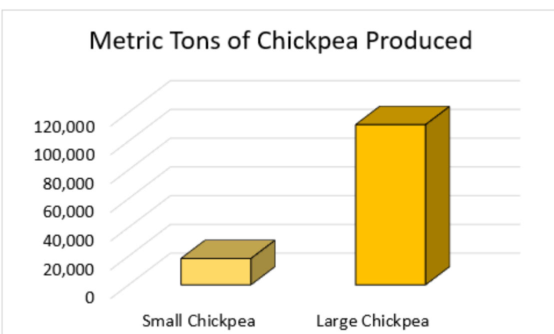


Table 1. United states pulses acreage and production summary for 2017-2021.

	2021		2020		2019		2018		2017	
Crop	Acreage*	Production**	Acreage*	Production**	Acreage	Production**	Acreage	Production**	Acreage	Production**
Dry Peas	834,000	387,780	919,000	941,571	1,052,000	1,135,229	836,400	635,936	1,108,900	648,251
Lentil	549,000	150,912	510,000	230,881	431,000	273,723	758,000	398,572	957,000	380,905
Chickpea	351,000	129,774	250,800	185,386	404,000	316,854	651,300	425,870	476,300	238,975
Total	1,734,000	668,466	1,679,800	1,357,838	1,887,000	1,725,806	2,245,700	1,460,378	2,542,200	1,304,132

*Acreage = Acres Harvested, **Production = Metric Tons, Source: USDA NASS (2021)/ 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 2021 (Table 2). For most analyses, data is provided on data collected between 2017 and 2021. The data is report as a range, mean and standard deviation (SD) for the 2021 harvest year while preceding years were provided as a means plus SD. Data on cultivars was reported only for the 2021 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. Generally, 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 dramatically 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, pea and lentil have fat contents under 3% while chickpea contain 5-10%.

- 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 mineral such as iron, zinc, and selenium. The specific mineral analysis provides information in mg/kg levels.

- 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 (GAC 2100) 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. The 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.

Table 2. Quality attribute, analytical method, and remarks for analyses conducted for the 2021 pulse quality survey.

Quality Attribute	Method	Remarks
1. Moisture (%)	AACC Approved Method of Analysis 44-15A	Indicator of post-harvest stability, milling yield and general processing requirements.
2. Protein (%)	AACC Approved Method of Analysis 46-30	Indicator of nutritional quality and amount of protein available for recovery.
3. Ash (%)	AACC Approved Method of Analysis 08-01	Indicator of total non-specific mineral content.
4. Total starch (%)	AACC Approved Method of Analysis 76-13	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 55-10	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 56-35.01	Indicator of cooking and canning behavior.
10. Unhydrated seed (%)	AACC Approved Method of Analysis 56-35.01	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 ($\Delta E^{*}ab$)	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 different heating profile and longer run time.	Indicator of texture, firmness, and gelatinization properties of the starch.
15. Cook Firmness	AACC Approved Method of Analysis 56-36.01	Indicator of pulse firmness after a cooking process. The information allows for a relative difference in texture to be established.
16. 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 38 dry pea samples were collected from Montana, North Dakota, and Washington from August to November 2021. Samples were delivered to SDSU between December 2021 and February 2022. Growing location, number of samples, market class, and genotype details of these dry pea samples are provided in Table 3. The majority of the dry pea samples were received from North Dakota. The majority of the pea samples were obtained from North Dakota and Washington. Green peas accounted for 12 of the samples collected, where Shamrock (4), Arcadia (3), and Scotch (2) accounted for the majority of the green peas evaluated. The remaining samples were a mix of various cultivars (Table 3).

Table 3. Description of dry pea samples used in the 2021 pulse quality survey.

State	No. of Samples	Market Class	Cultivars	
Montana	2	Green	Arcadia	
North Dakota	19	Green	Arcadia	Shamrock
		Yellow	AAC Chrome	AAC Profit
			AC Agassiz	CDC Inca
			Cronos	Durwood
			Pizzaz	Salamanca
			Spider	
Washington	17	Green	Ariel	Ginny
			Scotch	Columbian
		Winter	Blaze (Yellow)	
			Goldenwood (Yellow)	
			Vail (Green)	

Yellow peas accounted for 15 of the pea samples collected. Durwood (3) and Salamanca (2) made up five of the samples collected while the remaining samples were a mix of cultivars listed in table 3.

Winter (11) pea were also evaluated in 2021. The Vail cultivar accounted for the majorities of the samples evaluated.

Proximate composition of dry pea (Tables 4-6)

Moisture

The moisture content of dry pea ranged from 7.2-12.5% in 2021 (Table 4). The mean moisture content of all 38 pea samples was 9.7%, which is lower than the 5-year mean of 10.6% but comparable to the 10-year mean (9.6%). 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 2021, no samples had moisture contents greater than 13%. Most pea samples had moisture contents between 10 and 11%. The moisture contents of the green and yellow market classes were different by approximately 1.4 percentage points (Table 5). The green and yellow seed moisture of 9.4 and 10.8%, respectively, were both lower than the 5- and 10-year mean moisture contents of 10 and 9.9% and 11.5 and 11.2%, respectively, for green and yellow peas (Table 5). Winter peas had lower moisture percentages in 2021 compared to winter peas

Table 4. Proximate composition of dry pea grown in the USA, 2017-2021 and corresponding long-term means.

Proximate Composition (%)*	2021		2020	2019	2018	2017	5-year	10-year
	Range	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Moisture	7.2-12.5	9.7 (1.3)	9.5 (1.3)	12.4 (1.7)	9.6 (1.0)	9.5 (1.1)	10.3 (1.2)	9.6 (1.9)
Ash	2.3-3.0	2.6 (0.2)	2.5 (0.5)	2.4 (0.2)	2.5 (0.2)	2.5 (0.2)	2.5 (0.0)	2.5 (0.1)
Fat	0.6-1.2	1.0 (0.2)	1.7 (0.6)	2.0 (0.4)	2.8 (0.8)	2.1 (0.7)	nd	nd
Protein	20.6-26.7	23.1 (1.1)	21.4 (1.5)	21.0 (1.4)	21.4 (1.6)	21.5 (1.8)	21.4 (0.4)	22.3 (1.7)
Total Starch	40.2-49.9	42.9 (1.9)	44.4 (3.1)	43.3 (1.5)	42.5 (1.9)	41.9 (2.0)	43.1 (0.9)	44.7 (4.0)

*Composition is on an "as is" basis; nd = not determined due to test not being performed for 5 or 10 years.

from 2018 and 2019 but comparable moisture content to winter peas from 2020. The highest moisture contents were observed in the Shamrock (i.e., green pea) and Cronos (yellow pea) cultivars (Table 6). Most of the green peas had moisture contents in the 9 to 9.5% range while yellow peas had moisture contents between 10.4 and 11%. Winter peas had moisture values between 7.4 and 9.0%.

Table 5. Proximate composition of different market classes of dry pea grown in the USA, 2017-2021 and corresponding long-term means.

Proximate Composition (%)*	Mean (SD) of green pea					5-year Mean (SD)	10-year Mean (SD)
	2021	2020	2019	2018	2017		
Moisture	9.4 (0.9)	9.2 (1.3)	11.5 (1.8)	9.2 (1.1)	9.0 (1.1)	10 (1)	9.9 (1.0)
Ash	2.6 (0.2)	2.6 (0.3)	2.4 (1.8)	2.5 (0.2)	2.5 (0.2)	2.5 (0.2)	2.5 (0.1)
Fat	1.0 (0.2)	1.6 (0.6)	2.1 (0.3)	2.9 (0.8)	2.1 (0.7)	nd	nd
Protein	23.3 (1.0)	23.5 (1.3)	21.3 (0.2)	22.0 (1.8)	21.6 (2.0)	21 (2)	21.4 (0.4)
Total Starch	42.7 (1.4)	45.1 (3.0)	43.1 (1.5)	42.3 (1.6)	41.4 (2.1)	41 (3)	42.0 (0.8)
Proximate Composition (%)*	**Mean (SD) of yellow pea**					**5-year Mean (SD)**	**10-year Mean (SD)**
	2021	**2020**	**2019**	**2018**	**2017**		
Moisture	10.8 (0.6)	9.9 (1.1)	12.9 (1.4)	9.9 (0.9)	9.8 (0.9)	11.5 (1.1)	11.2 (1.2)
Ash	2.5 (0.1)	2.4 (0.6)	2.4 (1.2)	2.5 (0.2)	2.5 (0.2)	2.4 (0.2)	2.5 (0.1)
Fat	1.1 (0.1)	1.7 (0.6)	1.9 (0.4)	2.7 (0.8)	2.2 (0.8)	nd	nd
Protein	23.0 (1.0)	21.4 (1.3)	20.8 (0.2)	21.1 (1.5)	21.4 (1.7)	19.9 (1.7)	21.0 (0.8)
Total Starch	43.5 (2.5)	43.9 (3.0)	43.4 (1.5)	42.6 (2.0)	42.2 (1.9)	41.2 (4.7)	42.6 (0.9)
Proximate Composition (%)*	**Mean (SD) of winter pea**					**5-year Mean (SD)**	**10-year Mean (SD)**
	2021	**2020**	**2019**	**2018**	**2017**		
Moisture	8.4 (0.9)	7.8 (0.9)	9.5 (0.2)	9.5 (0.2)	**	nd	nd
Ash	2.7 (0.2)	2.5 (0.1)	2.5 (1.2)	2.5 (1.2)		nd	nd
Fat	0.8 (0.1)	1.7 (0.4)	1.9 (0.1)	1.9 (0.1)	**	nd	nd
Protein	23.1 (1.5)	21.3 (1.3)	21.3 (0)	21.3 (0)	**	nd	nd
Total Starch	43.5 (1.3)	46.1 (2.4)	42.5 (1.2)	42.5 (1.2)	**	nd	nd

*Composition is on an "as is" basis; **not previously reported; nd = not determined due to test not being performed for 5 or 10 years.

Ash

Ash content of dry pea ranged from 2.3 to 3.0%, with a mean of 2.6%. The mean ash content of dry peas grown in 2021 was the approximately the same as the 5- and 10-year mean ash contents (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 market classes were 2.6 and 2.5%, respectively (Table 5). The green and yellow pea ash contents were similar to their respective 5- and 10-year mean ash values of 2.5%. Winter peas had a 2.7% ash content, which was higher than the mean ash content from previous years (Table 5). Some variability in ash content was observed among cultivars (Table 6). The ash percentage in individual samples ranged from 2.4% in AAC profit and CDC Inca to 3.0% in Columbian. However, in winter cultivars the ash percentage was 2.5% for all samples.

Fat (Lipid)

Fat content of dry pea ranged from 0.6 to 1.2%, with a mean of 1.0%. The 2021 evaluation represents the fifth year of the fat analysis for the pea samples. Thus, no long-term data is available for comparison. However, the mean fat content of pea harvested in 2021 was lower than fat content of pea harvested in previous years. The fat contents of the green and yellow market classes were approximately the same and only slightly higher than fat contents in winter peas (Table 5). CDC Greenwater (green) and Delta (yellow) had the highest fat contents in their respective market classes (Table 6). In contrast, Scotch (green) and Goldenwood and Vail (winter) had the lowest and highest fat contents among the pea cultivars evaluated. Most yellow pea samples had fat contents of 1.0 to 1.1%, demonstrating the consistency in the fat content of the samples.

Protein

Protein content of dry pea harvested in 2021 ranged from 20.6 to 26.7% with a mean of 23.1% (Table 4). The mean protein content was higher than the 5- and 10-year mean protein contents of 21.4 and 22.3% (Table 4). The mean protein contents of the green, yellow, and winter pea samples were approximately 23%, with green peas having a slightly higher protein content (Table 5). Green pea samples had a mean protein content of 23.3% while the 5- and 10-year mean values were 21.0 and 21.4%, respectively. Yellow peas had a mean protein content (23%), which was higher than the 5- and 10-year mean protein contents of 19.9 and 21.0%, respectively (Table 5). Protein content of Winter peas was 23.1%, which was higher than the mean value of 21.3% for the previous three harvest years. Arcadia and Ariel (green, 23.8 and 21.8%, respectively) cultivars had the highest and lowest protein contents of the green peas. Spider and Salamanca cultivars had the highest and lowest protein contents of the yellow market classes (Table 6). In contrast, the winter peas had consistent protein contents (21.3-21.4%) among cultivars.

Table 6. Mean proximate composition of dry pea cultivars grown in the USA in 2021.

			Concentration (%)			
Market Class	Cultivar	Moisture	Ash	Fat	Protein	Starch
Green	Arcadia	9.8	2.6	1.1	23.8	43.1
	Ariel*	7.2	2.5	1.0	21.8	44.7
	Columbian*	9.1	3.0	0.7	22.7	41.8
	Ginny*	9.2	2.6	1.2	22.5	45.1
	Scotch	9.1	2.5	0.8	23.4	41.7
	Shamrock	10.0	2.6	1.0	23.6	42.0
Yellow	AAC Chrome*	10.9	2.6	1.1	22.3	49.9
	AAC Profit*	10.8	2.4	1.1	23.8	46.7
	AC Agassiz*	10.4	2.8	1.1	22.7	46.7
	CDC Inca*	10.6	2.4	1.0	23.2	42.0
	Cronos*	11.2	2.6	1.0	23.9	42.0
	Durwood	10.7	2.5	1.1	23.1	42.8
	Pizzaz*	10.8	2.5	1.1	23.5	41.9
	Salamanca	10.7	2.7	1.0	22.0	42.8
	Spider*	10.8	2.6	1.0	24.5	40.5
	Unknown	11.0	2.4	1.0	22.5	42.7
Winter	Blaze*	9.0	2.5	1.3	21.4	49.6
	Goldenwood*	7.4	2.5	1.9	21.3	44.9
	Vail	7.4	2.5	1.9	21.3	44.9

*Only one sample of cultivar tested

Total starch

Total starch content of dry pea ranged from 40.2 to 49.9% with a mean of 42.9% (Table 4). The mean total starch content of dry peas grown in 2021 was comparable to mean total starch in dry peas from the 2018 harvest year (i.e., 42.5%) and was lower than both the 5- and 10-year mean total starch values of 43.1 and 44.7%, respectively. The starch contents of the green and yellow market classes were 42.7 and 43.5%, respectively (Table 5). Green peas had a mean starch content that was higher than the 5- and 10-year mean values of 41.0 and 42.0%, respectively. The 5- and 10-year mean starch values for the yellow peas was lower (41.2 and 42.6%, respectively) than the mean starch content (43.5%) of yellow peas harvested in 2021. Unlike green peas, the peas from the 2021 most closely matched the peas harvested in 2019 and 2020. Winter peas from 2021 had a mean starch content (43.5%) that was substantially lower than winter peas from the 2020 harvest year (46.1%).

Ginny (green) and AAC Chrome (yellow) had the highest (45.1 and 49.9%, respectively) starch content among their respective market classes. The Blaze cultivar had the highest (49.6%) total starch among winter peas (Table 6). Scotch (41.7%), Spider (40.5%), and Goldenwood and Vail (44.9%) had the lowest starch contents in green, yellow, and winter peas, respectively (Table 6).

The general trend for all samples supports a higher protein and starch contents and lower fat contents in samples grown in 2021 compared to previous years. The drought conditions experienced in the summer of 2021 may have contributed to the observed effect of higher protein and lower starch contents. Evidence of higher protein and lower starch has been documented in other commodities such as wheat. The data presented here on the 2021 samples demonstrates similar impact on pulses. Furthermore, the support finding of other who showed that drought impacted the protein content of peas.

Physical parameters of dry pea (Tables7-11)

Test weight ranged from 62 to 67 lbs./Bu with a mean of 64.7 lbs./Bu. This mean value was the approximately 0.7 and 1.6 lbs./Bu higher than the 5- and 10-year mean values of 64 and 63.1 lbs./Bu (Table 7). The mean test weight for all pea samples harvested in 2021 was most comparable to those from 2019. The test weights of peas in the green and yellow market classes were 64.4 and 64.7 lbs./Bu, respectively (Table 8). These values were approximately 1 lbs./Bu higher than both the 5- and 10-year year mean values. Winter pea had the highest test weight at 65 lbs./Bu, which was identical to the winter peas from previous harvest years. The test weight of individual cultivars was comparable to one another within green and yellow market classes with few exceptions (Table 9). Shamrock (green) and AAC Chrome (yellow) had the highest test weights in their respective market classes. The lowest test weights were 63.4 and 62.0 lbs./Bu for the Scotch (green) and Cronos and Salamanca (yellow) cultivars, respectively (Table 9). The Goldenwood and Vail cultivars had comparable test weights of winter peas while Blaze had a slightly lower test weight.

Table 7. Physical parameters of dry pea grown in the USA, 2017-2021 and corresponding long-term means.

Physical Parameter	2021		2020	2019	2018	2017	5-year	10-year
	Range	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Test Weight (lb/bu)	62.0-67.0	64.7 (1.3)	63.6 (1.9)	64.3 (1)	63.5 (1)	63 (2)	64 (1)	63.1 (1.2)
1000 Seed Wt (g)	135-284	199 (40)	233 (33.0)	224 (31)	211 (33)	204 (32)	219(12)	216 (10)
Water Hydration Capacity (%)	91-110	100 (6)	97 (8.0)	96 (8)	103 (8)	104 (14)	99 (4)	101 (5)
Unhydrated Seeds (%)	0-5	0 (1)	2 (3)	2 (3)	1 (2)	2 (2)	2 (0)	2 (2)
Swelling Capacity (%)	129-169	146 (12)	118 (12.4)	145 (13)	147 (14)	148 (10)	139 (13)	nd
Cooked Firmness (N/g)	14.0-36.7	24.0 (5.2)	24.9 (6.3)	21.0 (7)	21.0 (5)	24 (6)	22.8 (1.8)	nd

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

Table 8. Physical parameters of different market classes of dry pea grown in the USA, 2017-2021 and corresponding long-term means.

Physical Parameter	Mean (SD) of green pea					5-year Mean (SD)	10-year Mean (SD)
	2021	2020	2019	2018	2017		
Test Weight (lb./Bu)	64.4 (1.9)	64 (2)	64 (1)	63 (1)	63 (2)	63 (0)	63 (1)
1000 Seed Wt. (g)	193 (26)	220 (31)	207 (28)	192 (28)	190 (28)	201 (14)	204 (12)
Water Hydration Capacity (%)	105 (3)	99 (7)	99 (6)	106 (8)	107 (20)	104 (4)	104 (5)
Unhydrated Seeds (%)	0 (0)	2 (2)	1 (1)	0 (1)	2 (2)	1 (1)	2 (2)
Swelling Capacity (%)	149 (12)	120 (12)	144 (10)	149 (12)	146 (11)	141 (12)	nd
Cooked Firmness (N/g)	21.4 (5.5)	21.7 (4)	18.9 (4.6)	19.8 (5)	22 (5)	21.3 (1.3)	nd
Physical Parameter	**Mean (SD) of yellow pea**					**5-year Mean (SD)**	**10-year Mean (SD)**
	2021	**2020**	**2019**	**2018**	**2017**		
Test Weight (lb./Bu)	64.7 (12)	63 (2)	64 (1)	63 (1)	63 (2)	64 (1)	63 (1)
1000 Seed Wt. (g)	235 (25)	244 (28)	222 (31)	214 (30)	231 (27)	227 (11)	224 (11)
Water Hydration Capacity (%)	95 (3)	93 (7)	102 (8)	102 (5)	95 (6)	99 (4)	100 (5)
Unhydrated Seeds (%)	1 (1)	2 (3)	0 (2)	1 (1)	2 (4)	1 (1)	2 (2)
Swelling Capacity (%)	137 (6)	116 (12)	146 (14)	150 (9)	135 (16)	139 (14)	nd
Cooked Firmness (N/g)	25.8 (5.4)	27.2 (6.6)	22.0 (7.1)	21.7 (5)	25 (6)	23.6 (2.4)	nd
Physical Parameter	**Mean (SD) of winter pea**					**5-year Mean (SD)**	**10-year Mean (SD)**
	2021	**2020**	**2019**	**2018**	**2017**		
Test Weight (lb./Bu)	65.0 (0.7)	65 (0.4)	65 (0)	**	**	nd	nd
1000 Seed Wt. (g)	156 (14)	175 (12)	154 (39)			nd	nd
Water Hydration Capacity (%)	103 (5)	96 (5)	85 (8)	**	**	nd	nd
Unhydrated Seeds (%)	0 (0)	1 (1)	7 (8)	**	**	nd	nd
Swelling Capacity (%)	156 (7)	119 (8)	131 (3)				
Cooked Firmness (N/g)	24.3 (3.7)	21.6 (1.6)	24.6 (8.3)	**	**	nd	nd

*Composition is on an "as is" basis; **not previously reported; 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 2021.

Market Class	Cultivar	Test Weight (lbs./Bu)	1000 Seed Weight (g)	Water Hydration Capacity (%)	Unhydrated Seeds (%)	Swelling Capacity (%)	Cooked Firmness (N/g)
Green	Arcadia	63.8	179	103	0	142	27.9
	Ariel*	63.8	168	105	1	165	21.6
	Columbian*	64.3	161	106	0	169	25.0
	Ginny*	62.9	182	104	1	141	19.3
	Scotch	62.3	186	102	0	160	21.9
	Shamrock	66.4	225	107	0	142	15.9
Yellow	AAC Chrome*	65.9	235	97	0	140	19.2
	AAC Profit*	64.4	245	96	1	130	25.1
	AC Agassiz*	64.5	229	99	2	146	19.1
	CDC Inca*	65.6	224	93	3	133	36.7
	Cronos*	63.4	283	95	0	143	18.2
	Durwood	65.6	231	93	1	132	27.9
	Pizzaz*	64.1	284	95	0	141	27.0
	Salamanca	63.4	230	101	1	144	27.7
	Spider*	65.1	256	94	2	138	25.4
	Unknown	64.5	207	92	2	134	25.9
Winter	Blaze*	64.0	173	106	0	166	23.4
	Goldenwood*	65.2	135	110	0	154	24.5
	Vail	65.1	156	102	0	155	24.4

*Only one sample of cultivar tested

The range and mean **1000 seed weight** of dry peas grown in 2021 were 135-284 g and 199 g, respectively (Table 7). The mean value (199 g) was lower than the 5- and 10-year mean 1000 seed weight of peas. This supports lighter seeds for the peas harvested in 2021. Peas of the green market class had a mean 1000 seed weight of 193 g, which is significantly lower than the 5- and 10-year mean value 1000 seed weight of 219 and 216 g, respectively (Table 8). Peas of the yellow market class had a mean 1000 seed weight of 235 g, which is slightly higher than the 5- and 10-year mean 1000 seed weight (Table 8). Winter pea samples harvested in 2021 had lower 1000 seed weight compared to peas harvested in 2020 but the was comparable to the 1000 seed weight from peas grown in 2019.

The individual cultivars (Table 9) varied extensively in 1000 seed weight, where cultivars in the green market class varied (161 to 225 g) more than cultivars in the yellow market class (224 to 284 g). This was the opposite of peas grown in 2020. Shamrock (225 g) and Pizzaz (284 g) and Columbian (161 g) and CDC Inca (224 g) had the highest and lowest 1000 seed weight in the green and yellow market class, respectively (Table 9). The overall lowest 1000 seed weight was observed in the winter pea cultivar Goldenwood. However, Vail (156 g) and Blaze (173 g) also had 1000 seed weights less the green and yellow peas. The test weight and 1000 seed weight support that the peas from 2021 tended to be smaller than the peas from previous crop years, with only a few exceptions.

The water absorption or hydration properties of peas is 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 91 to 110%, with a mean of 100% (Table 7). The 2021 mean value is comparable to the 5- and 10-year mean water hydration capacity of 99 and 101%, respectively. Peas from the 2020 harvest years had slightly lower water hydration capacity compared to peas from 2021. The mean water hydration capacity of peas in the green market class was ten and two percentage points higher than the mean hydration capacity of the yellow and winter market classes (Table 8). The mean water hydration capacity of the green peas in 2021 was comparable to the 5- and 10-year mean water hydration capacities (Table 8). The yellow peas from 2021 had a mean water hydration capacity that was lower than the 5- and 10-year mean water hydration capacities. In the green market class, Scotch and Shamrock had the lowest (102%) and highest (107%) water hydration capacities, respectively. In 2020, Shamrock also had the highest water hydration capacity. The water hydration capacity ranged from 92% in an unknown cultivar to 101% in the Salamanca cultivar (Table 9). The water hydration capacity (102-110%) of the winter pea samples demonstrates the consistency in water hydration capacities in 2021.

Unhydrated seed percentage ranged from 0-5% with a mean of 0%, which less than the 5- and 10-year mean unhydrated seed percentage (Table 7). Green and yellow peas had unhydrated seed values of 0 and 1%, respectively (Table 8). Winter peas also had 0% unhydrated seed. The green and yellow pea samples had lower unhydrated seed percentages as the 5- and 10-year mean value (Table 8). Most of the green pea cultivars had unhydrated seed rates of 0% while only

1% unhydrated seed rates were found in a few green cultivars (Table 9). Only a few yellow cultivars had 0% unhydrated seed counts. A one to three percent unhydrated seeds were observed in the yellow cultivars. CDC Inca had the highest unhydrated seed number at 3%. Overall, the low numbers (0-3%) 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 129% to 169% with a mean value of 146% (Table 7). The mean swelling capacity for peas from the 2021 harvest was slightly higher than the 5-year mean swelling capacities (Table 7). The mean swelling capacity was higher than the value reported for the 2020 samples but comparable to samples from previous harvest years. The swelling capacity of green peas was about 12 percentage point higher than the yellow pea (Table 8), but less than the 156% for the winter peas. The green and yellow peas had swelling capacities that were comparable to their respective 5-year mean swelling capacities. Variability in the swelling capacity among cultivars was observed (Table 9). Ginny (green) and AAC Profit (yellow) had the least swelling capacity. Columbian (green) and AC Agassiz (yellow) had the highest swelling capacities among the cultivars tested (Table 9). Blaze had the highest swelling capacity among winter peas.

The **cooked firmness** values were slightly higher in the peas from 2021 compared to those of 2018-2019 and the 5-year mean cooked firmness. The cooked firmness for all peas ranged from 14.0 to 36.7 N/g with a mean value of 24.0 N/g (Table 7). The cooked firmness of peas was different between market classes (Table 8). The green peas had lower firmness values than those of the yellow and winter peas. The value obtained in 2021 was comparable to the mean firmness value obtained from cooked green pea in 2017 but slightly higher than the 5-year mean vale. The cooked firmness values in yellow peas from 2021 were higher than 5-year mean firmness values. The winter peas had mean cooked firmness similar to peas from 2019. Among the green cultivars, Shamrock had the lowest cooking firmness (15.9 N/g) while Arcadia (25.5 N/g) was the firmest (Table 9). CDC Inca had the highest (36.7 N/g) cooking firmness among the yellow cultivars tested while Cronos (18.2 N/g) had the lowest cooked firmness (Table 9). The winter peas had cooked firmness values that ranged from 23.4 to 24.4 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 2021 indicated that the peas had L* values that were higher than the 5-year mean L* values and comparable to the 10-year mean L* value (Table 10). This observation was true for both green, yellow peas. The L* values for peas in 2021 matched the L* for peas from 2020. The winter peas were not grouped since

Table 10. Color quality of dry pea grown in the USA before and after soaking in water 16 hours, 2018-2021 and corresponding long-term means.

Color Scale*	Mean (SD) of green pea											
	Before Soaking						After Soaking					
	2021	2020	2019	2018	5-Year	10-Year	2021	2020	2019	2018	5-Year	10-Year
L (lightness)	57.34 (2.63)	58.82 (2.75)	48.99 (3.35)	51.68 (3.57)	52.84 (3.24)	57.55 (5.43)	53.41 (2.63)	54.69 (3.26)	50.42 (4.09)	45.49 (2.42)	49.00 (3.27)	52.59 (4.48)
a (red-green)	-2.21 (1.25)	-1.35 (1.97)	-2.46 (0.92)	-1.92 (0.77)	-1.59 (0.53)	-1.60 (1.56)	-7.43 (1.67)	-6.47 (3.45)	-6.28 (1.20)	-6.16 (0.77)	-5.86 (0.56)	-7.84 (2.74)
b (yellow-blue)	10.14 (1.28)	9.84 (1.51)	9.23 (0.92)	14.15 (1.49)	12.47 (2.43)	11.94 (2.62)	16.11 (2.57)	17.50 (3.24)	12.63 (2.25)	28.52 (2.65)	22.93 (6.62)	22.60 (6.38)
Color Difference	9.04 (2.18)	10.78 (1.93)	6.44 (3.05)	16.45 (2.53)	12.85 (3.75)	nd						
Color Scale	Mean (SD) of yellow pea											
	Before Soaking						After Soaking					
	2021	2020	2019	2018	5-Year	10-Year	2021	2020	2019	2018	5-Year	10-Year
L (lightness)	63.30 (1.01)	63.42 (2.64)	56.69 (2.98)	58.76 (2.39)	58.98 (2.36)	63.31 (5.07)	63.91 (0.64)	65.03 (1.47)	60.74 (2.03)	59.96 (1.98)	63.16 (3.65)	65.66 (4.83)
a (red-green)	4.29 (1.16)	4.99 (0.68)	4.97 (0.71)	6.91 (0.99)	6.17 (0.98)	5.84 (1.05)	5.16 (1.16)	5.50 (0.75)	3.89 (1.20)	9.38 (0.98)	7.00 (2.28)	6.15 (1.87)
b (yellow-blue)	11.73 (2.32)	14.61 (0.95)	14.48 (1.75)	19.21 (1.53)	17.61 (2.54)	17.26 (3.23)	22.06 (2.57)	28.89 (1.41)	21.15 (3.19)	37.67 (2.65)	32.53 (6.62)	32.37 (7.08)
Color Difference	13.53 (2.18)	14.63 (2.06)	8.46 (2.52)	19.10 (2.95)	16.16 (4.27)	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. nd = not determined due to test not being performed for 10 years.

the color included both yellow and green winter peas. Overall, the high L* indicates that the peas from the 2021 crop year were lighter in color than those from the 2018 and 2020 harvest years but comparable to the long term (10 year) seed lightness. The negative value for red-green (i.e., a* value) value in 2021 indicates more green color compared to samples from 2018 and 2020 but similar greenness to green peas from 2019 (Table 10). The a* value for green peas from 2021 was more negative compared to the 5- and 10-year mean a* values indicating that the peas were greener in nature compared to long term data. The b* values 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 pulses would be a dark green color. Therefore, the green peas in 2021 appear greener in color compared to those from previous years except 2019 and 2020. For the yellow pea market class, the 2021 crop had lightness values higher than previous pea samples except for the pea samples from 2020. Overall, the L* values from the 2021 pea samples matched the 10-year mean L* value and was higher than the 5-year mean L* value, indicating that the peas in 2021 were lighter than recent years but comparable to the long-term lightness value. 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 2021 had a* values that were similar to a* values in

Table 11. Color quality of USA dry pea cultivars before and after soaking, 2021.

		Mean Color Values*						
		Before Soaking			After Soaking			Color
Market Class	Cultivar	L	A	b	L	a	b	Difference
Green	Arcadia	60.08	-0.64	8.73	57.37	-4.80	13.44	7.12
	Ariel*	59.42	-2.12	8.99	50.76	-8.01	15.92	12.58
	Columbian*	59.18	-2.71	11.57	52.34	-9.13	18.07	11.43
	Ginny*	58.73	-2.31	10.01	54.96	-7.93	17.36	10.00
	Scotch	57.09	-1.61	11.52	52.63	-8.52	18.02	10.51
	Shamrock	54.10	-3.55	10.48	51.37	-8.17	16.40	8.03
Yellow	AAC Chrome*	64.20	4.15	10.97	63.80	4.58	19.24	8.30
	AAC Profit*	64.30	4.42	10.80	64.14	4.66	19.93	9.14
	AC Agassiz*	63.84	4.22	10.58	64.49	4.15	18.21	7.66
	CDC Inca*	62.87	4.36	10.92	63.45	4.83	19.51	8.62
	Cronos*	62.50	5.71	14.68	64.58	6.94	28.89	14.42
	Durwood	63.71	3.83	10.31	63.28	4.33	18.69	8.42
	Pizzaz*	63.65	6.05	15.57	64.67	7.63	31.44	15.98
	Salamanca	63.57	3.98	10.07	63.27	4.69	17.43	7.45
	Spider*	63.45	4.11	10.72	63.46	4.68	18.96	8.27
	Unknown	62.14	3.98	13.55	64.57	5.86	27.95	30.15
Winter	Blaze*	62.42	3.66	15.32	63.06	4.18	30.40	15.10
	Goldenwood*	57.88	1.04	13.70	58.70	-0.25	28.53	14.91
	Vail	53.64	-2.64	8.49	48.54	-8.30	15.69	10.52

*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.

peas from 2019 and 2020. The a* values for yellow peas from 2021 were less than the 5- and 10-year mean a* (Table 10). Similarly, the b* values for peas in 2021 were less than the 5- and 10-year mean b* values. This indicates that the yellowness of peas from 2021 was less than that of peas from previous years. 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 2021 appeared dark yellow to light brown in color compared to peas from previous years. The color of the dry peas changed after the soaking process. The change in color was less for green peas from the 2020 crop year compared to the previous crop years except 2019 (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 similar to previous crop years. In 2021, lightness increased only slightly after soaking of the yellow peas. However, these changes were less compared to the 5- and 10-year mean L*, a* and b* values. In addition, soaking caused a reduction in greenness (i.e., higher a* value) and increased yellowness (i.e., higher b* value) of the yellow peas. This suggests that the peas appeared more yellow after soaking (Table 10) but to a lesser degree compared to peas that make up the 5- and 10-year mean color values. The color difference test indicates a general change in color after soaking or other process. The green market class underwent less color change during soaking than did the yellow peas (Table 10). Although color difference is a general indicator of change, visual observations support a darkening of the green color in the green pea market class and an increase in yellowness after the soaking process in the yellow peas. The color difference values observed in 2021 were less than in samples from previous years except 2019. Less color differences were observed in both green and yellow pea samples compared to the 5-year mean color difference value. The Shamrock cultivar from 2021 had the lowest L* values (Table 11). Shamrock had the most negative a* value and one of the lowest b* values, giving it a dark green appearance. Arcadia had the highest L*, and a* values, giving it a light green appearance. The L* value decreased in all cultivars upon soaking. The a* values for all cultivars became more negative (i.e., greener) and more yellow (i.e., increased b* value). This combination of changes resulted in peas that appeared greener. The greatest color difference was observed in the Ariel cultivar while Arcadia underwent the least color change. The cultivars of the yellow peas had L* values between 62.50 and 64.30, with CDC Inca being the darkest and AAC Profit being the lightest (Table 11). Salamanca and Durwood retained the darkest color after soaking while Pizzaz became the lightest. Durwood had the lowest redness (a* value) while the highest was observed for the Pizzaz (Table

11). After soaking, AC Agassiz and Pizzaz cultivars had the lowest and highest redness values. The yellowness (b*) of the dry yellow pea was greatest for Pizzaz and lowest for Salamanca cultivars. After soaking, Pizzaz had the highest yellowness values while Salamanca had the lowest. Aside from an unknown cultivar, the greatest color difference was observed in the Pizzaz cultivar. The substantial increase in yellowness during soaking likely contributed to the greatest color difference for Pizzaz. Salamanca had the least color change during soaking.

As expected, Vail winter pea was darker, greener, and less yellow than the Goldenwood and Blaze since Vail is a green winter while Goldenwood and Blaze are yellow winter peas. The difference in color was more pronounced after soaking where Blaze and Goldenwood had a higher color difference score (Table 11). Vail did become greener after the soaking. The significant changes in the a* and b* values likely contributed to the color difference score in Vail.

Starch Properties (Tables 12-14)

The peas from 2021 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 value but was less than the 10-year mean peak time. This indicates that the samples begin to gel sooner than most samples from the 10-year period. Pasting temperature ranged from 77.5-85.7 °C, with a mean of 79.9°C. The mean value is slightly higher than the 5-year mean pasting temperature.

The starch characteristics were similar between the green and yellow pea market classes. However, pasting data for the green and yellow peas was higher than pasting data for the winter peas. Pea flour peak viscosities of 127 and 130 RVU were recorded for the green and yellow market classes, respectively (Table 13). These values were lower than the 5- and 10-year mean peak viscosity values for their respective market class. Other pasting properties followed the same trend where the 5- and 10-year mean viscosity were substantially higher than the values for pea from 2021. In contrast to green and yellow pea, the pasting characteristics of the winter pea samples were most comparable to winter peas from 2020 (Table 13). However, the pasting temperature was about 2°C higher for pea samples in 2021 compared to the peas from 2020. Collectively, the data indicates that significant changes in the starch, whether total starch content or alterations in the starch structure, may be the basis for the observation and that the drought likely impacted the starch during the growing season.

Within each market class, variability in starch characteristics was observed among cultivars. In the green pea, the Ariel cultivar had the highest peak, hot paste, and cold paste viscosities (Table 14). In contrast, the Scotch cultivar had the lowest peak, hot paste and cold paste viscosities. AAC Chrome had the highest peak, hot paste, and cold paste viscosities among yellow cultivars. The lowest peak, hot paste, and cold paste viscosities in the yellow market class were observed in the Spider cultivar (Table 14). The Blaze winter pea had higher peak, hot paste, and cold paste viscosities compared to the Goldenwood and Vail cultivars. However, type C pasting profile was demonstrated by all of the cultivars tested. This curve is represented by a minimally definable pasting peak, a small breakdown in viscosity and high final peak viscosity. The breakdown ranged from 3 to 20 RVU, which represents little breakdown of the starch paste. The setback values ranged from 57 to 186 RVU, which represents a significant setback for some of the samples. Collectively, these properties of the starch are ideal for glass noodle production.

Table 12. Starch characteristics of dry peas grown in the USA, 2017-2021 and corresponding long-term means.

Starch Characteristic	2021 Range	2021 Mean (SD)	2020 Mean (SD)	2019 Mean (SD)	2018 Mean (SD)	2017 Mean (SD)	5-Year Mean (SD)	10-Year Mean (SD)
Peak Viscosity (RVU)	84-179	126 (17)	134 (5)	146 (15)	139 (15)	139 (12)	140 (4)	146 (25)
Hot Paste Viscosity (RVU)	80-159	118 (15)	124 (14)	131 (12)	129 (13)	129 (10)	129 (3)	131(13)
Breakdown (RVU)	0-25	9 (5)	10 (5)	16 (6)	10 (5)	10 (5)	11 (3)	14 (10)
Cold Paste Viscosity (RVU)	123-345	204 (38)	229 (38)	233 (30)	235 (33)	232 (31)	233 (2)	244 (41)
Setback (RVU)	43-186	86 (24)	105 (26)	104 (22)	105 (22)	103 (23)	104 (1)	114 (31)
Peak Time (Minute)	5.00-6.73	5.37 (0.31)	5.29 (0.41)	5.11 (0.40)	5 (0)	5 (1)	5.20 (0.14)	6.14 (1.57)
Pasting Temperature (°C)	77.5-85.7	79.9 (1.8)	77.7 (1.8)	76.4 (1.3)	77.6 (2.1)	76 (3)	77.0 (0.8)	nd

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

Table 13. Starch characteristic of different market classes of dry peas grown in the USA, 2017-2021 and corresponding long-term means.

Starch Characteristics	Mean (SD) of green pea 2021	2020	2019	2018	2017	5-year Mean (SD)	10-year Mean (SD)
Peak Viscosity (RVU)	127 (23)	138 (16)	143 (17)	139 (15)	137 (12)	141 (4)	147 (28)
Hot Paste Viscosity (RVU)	120 (20)	127 (13)	127 (14)	128 (13)	127 (10)	128 (2)	130 (15)
Breakdown (RVU)	6 (5)	11 (3	16 (6)	11 (5)	10 (5)	13 (3)	15 (11)
Cold Paste Viscosity (RVU)	209 (53)	239 (40)	220 (32)	228 (38)	231 (34)	234 (12)	244 (45)
Setback (RVU)	89 (35)	112 (29)	93 (22)	101 (27)	104 (25)	106 (11)	115 (34)
Peak Time (Minute)	5.48 (0.40)	5.29 (0.30)	5.17 (0.35)	5 (1)	5 (1)	5.15 (0.15)	6.28 (1.49)
Pasting Temperature (°C)	80.4 (1.6)	78.3 (1.6)	76.8 (1.3)	78 (2)	78 (2)	77.1 (1.2)	78.0 (0.0)

Starch Characteristics	Mean (SD) of yellow pea 2021	2020	2019	2018	2017	5-year Mean (SD)	10-year Mean (SD)
Peak Viscosity (RVU)	130 (13)	132 (15)	148 (14)	140 (14)	140 (12)	141 (6)	144 (18)
Hot Paste Viscosity (RVU)	120 (12)	122 (13)	133 (10)	131 (12)	130 (10)	129 (4)	130 (9)
Breakdown (RVU)	9 (4)	13 (5)	16 (6)	9 (5)	10 (5)	12 (3)	15 (10)
Cold Paste Viscosity (RVU)	205 (30)	223 (34)	240 (27)	238 (29)	233 (28)	237 (10)	240 (34)
Setback (RVU)	84 (19)	101 (23)	110 (20)	108 (19)	103 (20)	108 (6)	111 (26)
Peak Time (Minute)	5.37 (0.14)	5.29 (0.48)	5.17 (0.35)	5 (1)	5 (1)	5.13 (0.15)	6.17 (1.55)
Pasting Temperature (°C)	79.9 (0.7)	77.2 (1.7)	76.2 (1.3)	77 (2)	78 (2)	76.7 (1.1)	76.5 (0.7)

Starch Characteristics	Mean (SD) of winter pea 2021	2020	2019	2018	2017	5-year Mean (SD)	10-year Mean (SD)
Peak Viscosity (RVU)	121 (14)	126 (11)	134 (19)	**	**	nd	nd
Hot Paste Viscosity (RVU)	111 (12)	113 (12)	118 (8)	**	**	nd	nd
Breakdown (RVU)	10 (6)	13 (2	16 (13)	**	**	nd	nd
Cold Paste Viscosity (RVU)	197 (28)	216 (33)	209(35)	**	**	nd	nd
Setback (RVU)	86 (19)	103 (22)	92 (28)	**	**	nd	nd
Peak Time (Minute)	5.25 (0.33)	5.18 (0.17)	5.58 (0.91)	**	**	nd	nd
Pasting Temperature (°C)	80.9 (2.2)	78.8 (1.4)	77.5 (1.5)	**	**	nd	nd

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

Table 14. Mean starch characteristics of dry pea cultivars grown in the USA in 2021.

Market Class	Cultivar	Peak Viscosity (RVU)	Hot Paste Viscosity (RVU)	Breakdown (RVU)	Cold Paste Viscosity (RVU)	Setback (RVU)	Peak Time (Min)	Pasting Temperature (°C)
Green	Arcadia	126	119	7	194	75	5.38	80.5
	Ariel*	179	159	20	345	186	5.13	79.1
	Columbian*	113	110	4	191	81	5.47	82.4
	Ginny*	116	111	5	206	95	6.73	80.6
	Scotch	98	92	6	148	57	5.44	82.3
	Shamrock	134	131	3	222	91	5.37	79.3
Yellow	AAC Chrome*	153	145	7	283	137	5.53	79.1
	AAC Profit*	126	118	8	191	73	5.27	78.4
	AC Agassiz*	132	124	8	221	97	5.13	80.0
	CDC Inca*	138	124	14	210	86	5.07	78.5
	Cronos*	133	122	11	208	86	5.33	78.4
	Durwood	127	116	11	197	81	5.27	78.1
	Pizzaz*	139	133	6	226	93	5.33	78.4
	Salamanca	126	115	11	197	82	5.23	79.2
	Spider*	118	113	5	177	64	5.27	78.3
	Unknown	126	117	9	191	74	5.18	78.6
Winter	Blaze*	130	122	8	242	119	5.33	79.2
	Goldenwood*	117	111	6	190	79	5.60	85.7
	Vail	120	110	11	193	83	5.41	80.6

*Only one sample of cultivar tested

Lentil Quality Results

Sample distribution

A total of 28 lentil samples were collected from Idaho, Montana, North Dakota, South Dakota, and Washington and delivered between December 2021 and February 2022. Growing location, number of samples, market class, and genotype details of these dry pea samples are provided in Table 17. Pardina (11) and Merrit (6) account for the majority of the lentil samples.

Table 15. Description of lentils used in the 2021 pulse quality survey.

State	No. of Samples	Market Class	Cultivars
Idaho	1	Spanish Brown	Pardina
Montana	1	Green	CDC Richlea
North Dakota	6	Green	CDC Greenstar
			CDC Invincible CL
			CDC Kermit
			CDC Viceroy
			ND Eagle
South Dakota	1	Red	CDC Maxim-CL
Washington	19	Green	Brewer
			Merrit
		Spanish Brown	Morena
			ND Eagle

Proximate composition of lentils (Tables 16-18)

Moisture

The moisture content of lentils ranged from 6.4 to 10.6% in 2021 (Table 16). The mean moisture content (8.0%) was slightly lower than the 5- and 10-year mean moisture content of 8.2% and was most similar to the mean moisture value of lentils from 2020, but lower than lentils from other years. Overall, all samples evaluated had moisture contents below the 13-14% recommended general storability. The moisture contents of the different market classes were between 7.6 and 10.6% (Table 17). The green lentils had a mean moisture content of 8.1% while red and Spanish brown lentils had moisture contents of 10.6 and 7.6%, respectively. The green lentils from 2021 had lower moisture contents than the five previous years and was 1.1 percentage points lower than the 5-year mean moisture content and 0.7 percentage points lower than the 10-year mean moisture content. The 2021 red lentils had higher moisture contents than lentils from the previous five and ten years. It should be noted that only one red lentil sample was evaluated in 2021 and thus the value could be different if more samples had been evaluated. Spanish brown lentils had a mean moisture content that was comparable to lentil from 2018 and 2020, but lower than lentils from other harvest years and was lower than the 5-year mean moisture content. The highest moisture contents were observed in the CDC Maxim CL (10.6%) cultivar (i.e., red lentil) while the Brewer (6.9%) cultivar (i.e., green lentil) had the lowest moisture content (Table 18). In 2020, Brewer also had one of the lowest moisture contents (7.0%).

Ash

Ash content of lentils ranged from 2.2 to 3.9% with a mean of 2.7% (Table 16). The mean ash content of lentils grown in 2021 was only slightly higher than the 5- and 10-year mean ash content of 2.5 and 2.6%, respectively. Ash content is a general indicator of minerals present. The mean ash contents of the green, red and Spanish brown market classes were 2.7, 2.5 and 2.8%, respectively (Table 17). The CDC Richlea and Merrit had the lowest (2.2%) and highest (3.0%) mean ash content among cultivars tested (Table 18).

Fat

Fat content of lentils ranged from 0.7 to 1.1% with a mean of 0.9% (Table 16). The fat content was measured in 2017 for the first time; thus, no 5- or 10-year mean value is available. However, lentils from the 2017 (2.1%) and 2018 (2.6%) harvest years were significantly higher than the mean fat content from 2021 while fat content in lentils from 2019 (1.1%) and 2020 (1.3%) were only slightly higher. Literature reports indicate that lentils have fat contents between 1 and 3%; therefore, the fat content of most of the lentils grown in 2021 falls below the lower end of the range reported by others. No difference in fat percentages were observed between the different market classes (Table 17). MCDC Greenstar (green) cultivar had the highest mean (1.1%) fat content while CDC Invincible (green), CDC Viceroy (green) and CDC Maxim-CL (Red) had the lowest (0.8%) fat content among cultivars (Table 18). This supports the consistent low fat content in lentils.

Table 16. Proximate composition of lentils grown in the USA, 2017-2021 and corresponding long-term means.

Proximate	2021		2020	2019	2018	2017	5-year	10-year
Composition (%)*	Range	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Moisture	6.4-10.6	8.0 (0.9)	8.2 (1.2)	9.8 (1.6)	8.4 (1.1)	8.8 (1.0)	8.2 (0.9)	8.2 (1.7)
Ash	2.2-3.9	2.7 (0.3)	2.6 (0.4)	2.4 (0.3)	2.6 (0.3)	2.5 (0.2)	2.5 (0.1)	2.6 (0.1)
Fat	0.7-1.1	0.9 (0.1)	1.3 (0.5)	1.1 (0.3)	2.6 (0.8)	2.1 (0.5)	nd	nd
Protein	21.6-26.6	24.5 (1.3)	24.8 (1.5)	24.3 (1.5)	24.4 (1.9)	23.5 (1.7)	23.7 (1.2)	23.6 (1.1)
Total Starch	39.2-46.8	43.0 (2.0)	44.4 (2.8)	42.8 (1.6)	44.0 (2.9)	44.0 (2.0)	43.7 (0.6)	44.6 (4.9)

*Composition is on an "as is" basis; nd = not determined due to test not being performed for 5 or 10 years.

Table 17. Proximate composition of different market classes of lentils grown in the USA, 2017-2021 and corresponding long-term means.

Market Class	Proximate Composition (%)*	Mean (SD)					5-Year	10-Year
		2021	2020	2019	2018	2017	Mean (SD)	Mean (SD)
Green	Moisture	8.1 (0.9)	8.5 (1.2)	10.3 (1.8)	8.8 (1.1)	9.0 (0.8)	9.2 (0.7)	8.8 (1.7)
	Ash	2.7 (0.3)	2.5 (0.5)	2.4 (0.2)	2.6 (0.4)	2.4 (0.2)	2.5 (0.1)	2.5 (0.2)
	Fat	0.9 (0.1)	1.3 (0.5)	1.1 (0.4)	2.8 (0.8)	2.1 (0.5)	nd	nd
	Protein	24.9 (1.3)	24.5 (1.6)	24.8 (1.5)	24.2 (2.0)	23.2 (1.7)	23.6 (1.4)	23.4 (1.2)
	Total Starch	42.0 (1.3)	44.7 (2.9)	42.1 (1.4)	44.1 (3.4)	44.0 (2.1)	43.6 (1.0)	44.8 (5.0)
Red**	Moisture	10.6 (0)	7.9 (1.2)	8.8 (1.0)	7.6 (1.1)	8.6 (1.2)	8.4 (0.7)	8.3 (1.6)
	Ash	2.5 (0)	2.7 (0.3)	2.4 (0.3)	2.8 (0.1)	2.5 (0.2)	2.6 (0.2)	2.7 (0.2)
	Fat	0.8 (0)	1.3 (0.4)	1.2 (0.3)	2.1 (0.3)	2.0 (0.5)	nd	nd
	Protein	25.1 (0)	26.3 (0.9)	24.7 (0.8)	26.0 (0.6)	24.3 (1.5)	24.9 (1.2)	24.4 (1.4)
	Total Starch	39.2 (0)	43.6 (4.1)	42.8 (0.7)	42.8 (1.2)	43.9 (2.0)	43.6 (0.9)	44.4 (4.6)
Spanish Brown	Moisture	7.6 (0.4)	7.5 (0.8)	9.8 (1.2)	7.8 (0.8)	8.2 (0.7)	8.2 (0.9)	nd
	Ash	2.8 (0.4)	2.6 (0.1)	2.4 (0.3)	2.6 (0.2)	2.7 (0.2)	2.6 (0.1)	nd
	Fat	0.9 (0.1)	1.6 (0.4)	1.1 (0.2)	2.0 (0.5)	2.2 (0.5)	nd	nd
	Protein	23.9 (1.3)	24.9 (0.9)	23.5 (1.2)	24.3 (1.4)	23.6 (1.2)	23.4 (1.6)	nd
	Total Starch	44.6 (1.5)	43.9 (1.8)	43.9 (1.5)	44.4 (1.2)	43.9 (1.7)	43.4 (1.3)	nd

*As is basis; **based on 1 sample in 2021; nd = not determined due to test not being performed for 5 or 10 years.

Protein

Protein content of lentils ranged from 21.6 to 26.6% with a mean value of 24.5%. The mean protein content of lentils grown in 2021 was higher than the 5-and 10-year mean protein contents of 23.7% and 23.6%, respectively. The protein contents of the three market classes were different (Table 17). Red lentils had the highest mean protein content (25.1%) among the lentil market classes while the Green and Spanish brown lentils had mean protein values of 24.9 and 23.9%, respectively. The mean protein contents of the green and red lentils from 2021 were higher than their respective 5- and 10-year mean protein content. The Merrit (green) and CDC Greenstar (green) cultivars had the highest and lowest protein percentage, respectively, among known cultivars (Table 18).

Table 18. Mean proximate composition of lentil cultivars grown in the USA in 2021.

		Concentration (%)				
Market Class	**Cultivar**	**Moisture**	**Ash**	**Fat**	**Protein**	**Starch**
Green	Brewer	6.9	2.5	1.0	25.5	41.9
	CDC Greenstar*	9.9	2.7	1.1	21.6	44.3
	CDC Invincible CL	8.5	2.4	0.8	24.9	42.3
	CDC Kermit*	8.5	2.5	0.9	24.8	42.4
	CDC Richlea*	9.2	2.2	0.9	22.5	43.6
	CDC Viceroy*	8.8	2.3	0.8	25.2	42.1
	Merrit	7.6	3.0	0.9	25.7	41.1
	ND Eagle*	8.8	2.5	0.9	24.1	43.1
Red	CDC Maxim-CL*	10.6	2.5	0.8	25.1	39.2
Spanish Brown	Morena*	7.4	2.7	1.0	25.2	43.1
	Pardina	7.6	2.8	0.9	23.8	44.7

*Only one sample of cultivar tested

Total starch

Total starch content of lentils ranged from 39.2 to 46.8%, with a mean of 43.0% (Table 16). The mean total starch percentage of lentils grown in 2021 was lower than starch percentage in lentils from the previous five and ten years. The mean 5- and 10-year mean starch contents were 43.7 and 44.6%, which supports the lower starch observed in other pulses in 2021. The only exception to this observation was for the Spanish brown market class which had higher (44.6%) starch content in 2021 compared to the 5-year mean starch or 23.4% (Table 17). The mean starch contents of the lentils in the green and red market classes were 42.0 and 32.9%, respectively (Table 17). The mean starch percentage for green lentil from 2021 was most comparable to lentils from 2019 but was lower in lentils from other harvest years including the 5- and 10-year mean starch contents. Lentils from the red market class in 2021 tended to significantly lower percent starch than lentils from other harvest years (Table 17). The highest mean starch content was observed in Pardina (Spanish brown) cultivar at 44.7% (Table 18). The CDC Maxim-CL (39.2%) cultivar had the lowest mean starch content among known cultivars tested (Table 18).

Physical parameters of lentils (Tables 19-23)

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 59.2-68.5 lbs./Bu with a mean of 64.3 lbs./Bu. This mean value was the same as the mean test weight from 2020 and higher than the 5- and 10-year mean test weight of 62.7 and 62.1 lbs./Bu, respectively (Table 19). Similar to 2020, the mean test weight of lentils in the Spanish brown market class was approximately 2 percentage points higher than test weights of lentils from the green and red market classes (Table 20). Regardless of the market class, the mean test weight for lentils in 2021 were higher than their respective 5- and 10-year mean test weights. The highest test weight of 66.9 lbs./Bu was observed in the Morena cultivar. Merrit (59.7 lbs./Bu) had the lowest test weight values (Table 21). The Merrit cultivar also had the lowest mean test weight (61.7 lbs./Bu) in 2020 among the green lentils.

Table 19. Physical parameters of lentils grown in the USA, 2017-2021 and corresponding long-term means.

Physical Parameters	2021 Range	2021 Mean (SD)	2020 Mean (SD)	2019 Mean (SD)	2018 Mean (SD)	2017 Mean (SD)	5-year Mean (SD)	10-year Mean (SD)
Test Weight (lb/Bu)	59.2-68.5	64.3 (2.9)	64.3 (2.0)	62.4 (2.5)	62.9 (2.2)	62 (2)	62.7 (0.9)	62.1 (1.2)
1000 Seed Wt (g)	28-72	45 (13)	48.0 (10.0)	42.8 (10.8)	42 (9)	44 (9)	44 (2)	45 (2)
Water Hydration Capacity (%)	71-102	87 (8)	91 (21)	91 (8)	99 (2)	101 (3)	95 (5)	96 (9)
Unhydrated Seeds (%)	0-12	4 (4)	5 (6)	4 (4)	2 (3)	1 (2)	3 (2)	4 (2)
Swelling Capacity (%)	67-128	98 (15)	117 (21)	143 (15)	140 (15)	144 (28)	137 (11)	nd
Cooked Firmness (N/g)	12.6-28.7	19.8 (4.2)	19.9 (4.3)	15.8 (4.8)	15 (3)	14.9 (3.9)	15.8 (2.5)	nd

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

The range and mean **1000 seed weight** of lentils grown in 2021 were 28 to 72 g and 45.0 g, respectively (Table 19). The mean value was comparable to the 5- and 10-year mean values of 44-45 g. Lentils of the red market class had a mean 1000 seed weight of 63 g, which was higher than the 5- and 10-year mean values of 39 and 43 g, respectively. The significant difference might reflect that only one red lentil was used in the calculations in 2021. Lentils from the green market class had a mean 1000 seed weight of 51 g, which is identical to the mean 1000 seed weights for green lentils grown in 2020. Furthermore, the mean 1000 seed weight is slightly higher than the 5- and 10-year mean values (Table 20). The lentils from the green and red market class supports larger seed size compared to previous evaluations while lentils from the Spanish brown market class represent a smaller seed size in lentils from 2021. This is supported by the lower (35 g) 1000 seed weight in 2021 compared to the 5- and 10-year mean values. CDC Kermit (28g) and CDC Invincible (30 g) had the lowest 1000 seed weights (Table 21). CDC Richlea (72 g) had the highest 1000 seed weight among lentils from 2021.

Water hydration capacity of lentils ranged from 71 to 102%, with a mean of 87% (Table 19). The 2021 mean water hydration capacity value were lower than lentils from recent years, including the 5- and 10-year mean water hydration capacity. The water hydration capacity (93%) was highest for red lentils while the green (85%) and Spanish brown (88%) market classes had slightly lower water hydration capacities (Table 20). Except for the Spanish brown lentils, lentils from 2021 had water hydration capacities that were significantly lower than the 5- and 10-year mean values from their respective classes. Spanish brown lentils had comparable water hydration capacity to the 5-year mean value (Table 20). The mean water hydration capacity ranged from 77% in Merrit to 102% in CDC Kermit. Most other cultivars had water hydration capacities of approximately 90 to 95% (Table 21).

Table 20. Physical parameters of different market classes of lentils grown in the USA, 2017-2021 and corresponding long-term means.

Market class	Physical Parameters	Mean (SD) 2021	2020	2019	2018	2017	5-Year Mean (SD)	10-Year Mean (SD)
Green	Test Weight (lb./Bu)	62.3 (2.5)	63.6 (1.8)	61.8 (2.4)	62.2 (1.8)	61 (2)	62.1 (0.9)	62.0 (0.9)
	1000 Seed Wt. (g)	51 (13)	51 (10)	46 (12)	47 (8)	48 (8)	48 (2)	45 (6)
	Water Hydration Capacity (%)	85 (9)	88 (11)	93 (6)	100 (9)	103 (10)	107 (22)	100 (20)
	Unhydrated Seeds (%)	3 (3)	6 (7)	2 (2)	1 (1)	1 (1)	2 (2)	4 (4)
	Swelling Capacity (%)	97 (13)	117 (18)	145 (11)	140 (15)	144 (18)	131 (20)	nd
	Cooked Firmness (N/g)	19.7 (4.7)	19.2 (4.2)	15.5 (5.3)	14.5 (3.8)	15.1 (4.4)	15.6 (2.2)	nd
Red*	Test Weight (lb./Bu)	64.7 (0)	63.9 (2.5)	64.2 (0.4)	61.6 (2.1)	63 (3)	63.1 (1.0)	62.1 (1.9)
	1000 Seed Wt. (g)	63 (0)	43 (9)	36.8 (6)	41 (5)	36 (6)	39 (3)	43 (7)
	Water Hydration Capacity (%)	93 (0)	126 (41)	84 (8)	106 (12)	95 (16)	111 (22)	103 (17)
	Unhydrated Seeds (%)	3 (0)	5 (6)	8 (1)	1 (1)	2 (2)	4 (3)	4 (2)
	Swelling Capacity (%)	128 (0)	138 (35)	140 (5)	143 (15)	132 (11)	136 (7)	nd
	Cooked Firmness (N/g)	19.6 (0)	21.7 (5.3)	14.8 (5.7)	15.2 (3.5)	14.9 (2.2)	16.0 (3.3)	nd
Spanish Brown	Test Weight (lb./Bu)	66.7 (0.7)	66.1 (1.0)	62.4 (2.0)	65.4 (0.6)	64 (2)	64.8 (1.6)	64.8 (1.4)
	1000 Seed Wt. (g)	35 (3)	42 (4)	43 (7)	32 (2)	40 (10)	39 (5)	38 (4)
	Water Hydration Capacity (%)	88 (6)	81 (13)	91 (8)	93 (10)	102 (15)	89 (2)	94 (15)
	Unhydrated Seeds (%)	6 (3)	5 (4)	3.9 (6)	6 (3)	3 (4)	6 (4)	5 (4)
	Swelling Capacity (%)	97 (16)	109 (15)	143 (21)	137 (16)	144 (18)	130 (16)	nd
	Cooked Firmness (N/g)	19.8 (4.0)	21.7 (3.9)	15.8 (2.8)	15.5 (1.8)	13.6 (3.3)	15.9 (3.4)	nd

*Based on 1 sample in 2021; nd = not determined due to test not being performed for 5 or 10 years.

Unhydrated seed percentage ranged from 0 to 12% with a mean of 4 %, which is less than the 5- and 10-year mean of 3 and 4%, respectively (Table 19). Unlike 2020, there were no samples that had exceedingly high (greater than 20%) unhydrated seed percentage in 2021. Given the drought of 2021, we had expected that the seeds would be impacted due to the dryness of the seed. However, this was found not to be true. The mean unhydrated seeds in all market classes varied from 3 to 6% (Table 20). The green and red lentils from 2021 had mean unhydrated seed percentage that was comparable to the 5- and 10-year mean unhydrated seed percentage. For Spanish brown, the unhydrated seed count in was the same are the 5-year and 10-year mean unhydrated seed percentage. This indicates that the drought conditions did not impact this quality trait of the different market classes. Several cultivars had no unhydrated seed percentage while the Morena cultivar had the highest at 9% (Table 21).

The **swelling capacity** of all lentils ranged from 67 to 128%, with a mean value of 98% (Table 19). The mean swelling capacity from 2021 samples were significantly lower than that of lentils from the previous years, including the 5-year mean swelling capacity. This observation coincided with the water hydration capacity and supports that the dry growing conditions likely affected the lentil compositionally and structurally and inhibited water uptake, which is important for a full rehydration of the seed and the accompanying swelling of the seed. The swelling capacity of lentils was similar between the green and Spanish brown market classes (Table 20). However, the red market class had the highest swelling capacity at 128%. Swelling capacities of the green and Spanish brown lentils were significantly lower than their respective 5-year mean swelling capacities. In contrast, the swelling capacity of the red lentils was slightly lower than the 5-year mean swelling capacity (Table 20). CDC Maxim-CL had the greatest swelling capacity (128%). This same cultivar had the highest swelling capacity in 2020. The Morena brown lentil had the lowest (67%) swelling capacity among all cultivars (Table 21). The low swelling capacity for Morena lentils was likely due to the low water uptake as supported by the high number of unhydrated seeds and low water hydration capacity.

Table 21. Mean physical parameters of USA lentil cultivars grown in 2021.

Market Class	Cultivar	Test Weight (lb/bu)	1000 Seed Wt (g)	Water Hydration Capacity (%)	Unhydrated Seeds (%)	Swelling Capacity (%)	Cooked Firmness (N/g)
Green	Brewer	62.3	48	86	6	92	21.9
	CDC Greenstar*	61.9	67	94	1	108	22.1
	CDC Invincible CL	65.6	30	93	2	83	13.4
	CDC Kermit*	65.8	28	102	1	85	12.6
	CDC Richlea*	63.6	72	79	0	111	23.6
	CDC Viceroy*	65.7	52	88	2	119	14.4
	Merrit	59.7	58	77	5	93	22.4
	ND Eagle*	63.6	50	97	1	122	17.9
Red	CDC Maxim-CL*	64.7	63	93	0	128	19.6
Spanish Brown	Morena*	66.9	36	80	9	67	20.6
	Pardina	66.7	35	89	5	99	19.7

*Only one sample of cultivar tested

The **cooked firmness** of all lentils ranged from 12.6 to 28.7 N/g with a mean value of 19.8 N/g (Table 19). The lentils from 2020 had similar cooked firmness values to lentils from 2020 but significantly greater values than lentils from the other harvest years, including the 5-year mean cooked firmness. The cooked firmness of lentils was not substantially different between the market classes (Table 20). Regardless of the market class, the cooked firmness was higher in lentils harvested in 2021 compared to the 5-year mean cooked firmness. Among the cultivars, CDC Richlea had the highest cooked firmness value while CDC Kermit and CDC Invincible CL had the lowest cooked firmness values (Table 21).

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 22). Color quality for all lentils in 2021 indicated that the lentils had higher L* values than in lentils from previous years except 2020. This data indicates that the lentils from the 2021 crop year were lighter in color than those from previous years. However, the L* value of the green lentils was essential the same as the 10-year mean L* value (Table 22). The lower a* value (i.e., green-red scale) in the green lentil indicates a less red color while a more negative a* value for the green lentils indicates a greener color. In 2021, the a* value of 3.20 indicates that the lentils were less green in 2021 compared to lentils from recent harvest years, including lentils used to determine the 5- and 10-year mean a* values. In the red lentil market class, the 2021 sample was less red based on the lower a* value compared the 5- and 10-year mean a*values. The mean a* value for the Spanish brown lentils was comparable to the 5-year mean a* value indicating similar redness. The green lentils had a lower mean b* value than the 5- and 10-year mean values suggesting the 2021 samples are less yellow in nature. Similar trend of lower b* values was observed in the red lentil and would lead to a lentil with darker red color compared to a sample that had higher b* values (Table 22). The Spanish brown b* value was lower in the 2021 samples compared to the 5-year mean b* values. This indicates that the lentils were a darker brown compared to previous years except 2020.

The color of the lentils changed after the soaking process. Red and Spanish brown market classes became lighter as evidenced by the slightly higher L* values (Table 22) compared to pre-soaked lentils. However, the lightness value decreased in the green market class after soaking. In the green and Spanish brown market classes, the decreased a* value indicated an increase in greenness of the lentils after soaking. In the red lentil market class, a* increased suggesting more redness was observed in lentil after soaking, however the change was not as extensive when compared to the 5– and 10-year mean values. Lentils from all

Table 22. Color quality of lentils grown in the USA before and after soaking, 2018-2021 and corresponding long-term means.

Color Scale*	Mean (SD) of green lentils											
	Before Soaking						After Soaking					
	2021	2020	2019	2018	5-Year	10-year	2021	2020	2019	2018	5-Year	10-Year
L (lightness)	57.10 (0.96)	59.75 (1.45)	48.07 (1.91)	53.97 (3.25)	54.63 (4.25)	57.34 (4.27)	56.69 (2.59)	60.15 (3.93)	52.93 (1.52)	57.69 (1.36)	57.25 (2.66)	59.45 (3.62)
a (red-green)	3.20 (1.85)	0.83 (1.05)	0.53 (1.43)	4.34 (1.21)	3.14 (2.28)	2.47 (1.74)	2.00 (1.35)	-0.12 (4.00)	-0.98 (2.86)	3.86 (1.34)	2.31 (2.64)	1.31 (2.09)
b (yellow-blue)	12.22 (2.10)	15.39 (0.95)	13.54 (3.45)	21.28 (1.51)	19.10 (4.33)	19.24 (4.01)	14.23 (3.89)	20.48 (5.52)	20.48 (2.35)	30.73 (2.39)	27.19 (6.16)	27.21 (5.20)
Color Difference	5.57 (1.48)	8.23 (4.79)	9.31 (3.40)	10.54 (3.35)	9.66 (0.94)	nd						
Color Scale**	**Mean (SD) of red lentils**											
	Before Soaking						After Soaking					
	2021	2020	2019	2018	5-Year	10-Year	2021	2020	2019	2018	5-Year	10-Year
L (lightness)	53.60 (0)	55.13 (2.32)	44.84 (2.08)	51.13 (4.17)	48.65 (4.36)	51.91 (4.58)	54.52 (0)	55.05 (3.93)	48.83 (2.48)	53.01 (3.24)	51.01 (2.83)	52.06 (2.62)
a (red-green)	3.47 (0)	2.88 (1.91)	3.38 (0.60)	7.38 (0.50)	5.80 (2.46)	5.05 (1.87)	5.48 (0)	5.36 (3.42)	9.35 (1.84)	13.63 (1.12)	10.96 (3.61)	9.63 (2.88)
b (yellow-blue)	5.29 (0)	11.07 (4.09)	9.36 (1.49)	21.28 (1.51)	13.22 (3.11)	12.42 (3.96)	10.21 (0)	14.67 (2.55)	19.05 (2.52)	28.44 (2.11)	23.48 (6.26)	22.47 (5.05)
Color Difference	5.40 (0)	7.40 (3.28)	12.12 (1.96)	13.02 (3.76)	12.59 (3.24)	nd						
Color Scale	**Mean (SD) of brown lentils**											
	Before Soaking						After Soaking					
	2021	2020	2019	2018	5- Year	10-Year	2021	2020	2019	2018	5-Year	10-Year
L (lightness)	51.11 (0.47)	51.97 (0.33)	39.52 (2.39)	42.71 (6.78)	44.34 (4.64)	nd	52.42 (1.22)	53.96 (0.44)	39.03 (3.65)	49.42 (1.75)	47.83 (5.44)	nd
a (red-green)	3.17 (0.26)	0.66 (1.48)	1.72 (0.58)	5.01 (0.63)	3.74 (2.40)	nd	2.99 (0.56)	-0.90 (0.70)	2.93 (1.25)	7.08 (0.39)	4.67 (3.62)	nd
b (yellow-blue)	6.93 (0.47)	8.60 (1.58)	6.48 (1.63)	12.35 (1.57)	10.54 (2.87)	nd	11.96 (4.85)	10.13 (1.54)	14.69 (1.34)	29.33 (2.55)	21.85 (8.83)	nd
Color Difference	5.58 (4.33)	3.53 (1.79)	8.72 (1.03)	19.01 (5.74)	12.60 (6.32)	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. **based on one sample in 2021. nd = not determined due to test not being performed for 5 or 10 years.

market classes became more yellow (i.e., increased b value) after soaking. The color difference in lentil samples was comparable among market class (Table 22). Overall, the colors were less impacted by soaking in comparison to lentils from previous years as represented by smaller color difference values compared to the 5- and 10- years mean color difference values.

Among the cultivars, Morena and Pardina had the lowest L* value followed by CDC Maxim-CL (Table 23). The highest L* was observed in the CDC Invincible CL green lentil. This follows expectations that the brown and red lentils would be darker than the green lentils. The L* values of lentil increased for the red and brown lentils after soaking. In contrast, about 50% of green cultivars had higher L* after soaking (Table 23). The green and Spanish brown lentil cultivar became greener (i.e., reduction of the a* value) after soaking while the red intensity (increased a* value) of the red cultivars increased during soaking. CDC Viceroy had the greenest color after soaking while CDC Maxim had the highest red value. The b* value increased substantially in all lentils during soaking except for Brewer, CDC Greenstar, CDC Kermit, and Morena. The green lentil cultivar Merrit 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 greatest color difference was observed the CDC Viceroy cultivar (Table 23). The increase in lightness, greenness, and yellowness during soaking likely contributed to the greatest color difference in this cultivar. The color of Morena was the most stable as this cultivar had the lowest color difference value (i.e., 1.14).

Table 23. Color quality of USA lentil cultivars before and after soaking, 2021.

		Mean Color Values*						
		Before Soaking			After Soaking			Color
Market Class	Cultivar	L	a	b	L	a	b	Difference
Green	Brewer	56.13	5.68	12.52	53.74	3.30	10.02	4.25
	CDC Greenstar**	55.39	2.15	15.97	55.56	1.26	12.65	5.95
	CDC Invincible CL	58.45	0.90	14.19	53.70	0.65	11.75	5.46
	CDC Kermit**	57.73	0.93	14.37	54.78	0.50	12.54	3.51
	CDC Richlea**	58.09	1.86	9.18	59.43	0.89	13.44	4.58
	CDC Viceroy**	56.71	1.03	8.86	60.49	-0.24	14.74	7.11
	Merrit	56.94	4.44	12.15	58.03	3.11	17.46	6.59
	ND Eagle**	57.71	2.34	8.65	57.06	1.04	11.80	3.47
Red	CDC Maxim-CL**	53.60	3.47	5.29	54.52	5.48	10.21	5.40
Spanish Brown	Morena**	51.04	2.62	6.34	51.92	2.06	6.33	1.14
	Pardina	51.12	3.22	6.98	52.47	3.08	12.47	5.99

*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 24-26)

Peak, hot paste and cold paste viscosities of lentils grown in 2021 were significantly lower to their respective values from lentils of other harvest years. For example, a significantly lower cold paste viscosity (210 RVU) was observed for lentils from 2021 (Table 24) compared to other harvest years and the 5- and 10-year mean cold paste viscosities. The lower pasting viscosities follow the same trend as the 2021pea samples. Pasting temperature ranged from 76.7 to 84.8 °C, with a mean value of 80 °C, which is higher than the 5-year mean pasting temperature. Unlike 2020, the peak, hot paste and cold paste viscosities were different among the market classes (Table 25). The peak, hot paste and cold paste viscosities obtained for lentils in the red market class were lower than the lentils in other market classes. This general observation was also observed in samples from 2020. This suggests a thinner final viscosity for red lentil flours. Pasting characteristics for all market class in 2021 were lower than the 5-year mean viscosity value 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 2021 produce thinner pastes and gels.

Table 24. Starch characteristics of lentils grown in the USA, 2017-2021 and corresponding long-term means.

Starch Characteristic	2021		2020	2019	2018	2017	5-year	10-year
	Range	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Peak Viscosity (RVU)	63-149	117 (23)	142 (21)	146 (14)	142 (18)	143 (17)	144 (3)	139 (20)
Hot Paste Viscosity (RVU)	61-140	110 (23)	133 (17)	137 (11)	134 (14)	136 (15)	135 (2)	128 (12)
Breakdown (RVU)	1-29	7 (7)	9 (6)	9 (6)	8 (6)	7 (4)	10 (3)	12 (11)
Cold Paste Viscosity (RVU)	116-290	210 (50)	237 (35)	253 (28)	245 (29)	253 (28)	246 (8)	236 (37)
Setback (RVU)	48-150	100 (28)	104 (21)	117 (19)	111 (16)	117 (16)	111 (6)	109 (27)
Peak Time (Minute)	4.73-7.00	6.10 (0.76)	5.68 (0.62)	5.49 (0.52)	5.85 (0.76)	5.65 (1)	5.57 (0.26)	6.67 (1.66)
Pasting Temperature (°C)	76.7-84.8	80.0 (1.8)	78.9 (1.5)	77.1 (1.2)	77.8 (1.8)	77.8 (2)	77.5 (1.1)	nd

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

Table 25. Starch characteristic of different market classes of lentils grown in the USA, 2017-2021 and corresponding long-term means.

Market class	Starch Characteristics	Mean (SD)					5-Year Mean (SD)	10-Year Mean (SD)
		2021	2020	2019	2018	2017		
Green	Peak Viscosity (RVU)	111 (22)	146 (21)	142 (13)	145 (18)	146 (16)	146 (3)	144 (51)
	Hot Paste Viscosity (RVU)	103 (21)	135 (17)	133 (8)	134 (14)	138 (13)	134 (2)	131 (44)
	Breakdown (RVU)	8 (9)	10 (6)	8 (5)	10 (6)	8 (5)	11 (4)	13 (12)
	Cold Paste Viscosity (RVU)	193 (41)	241 (35)	242 (26)	248 (30)	256 (5)	245 (7)	242 (86)
	Setback (RVU)	90 (21)	106 (22)	109 (19)	113 (17)	118 (16)	110 (5)	96 (37)
	Peak Time (Minute)	6.11 (0.83)	5.54 (0.55)	5.53 (0.54)	5.59 (0.16)	5.58 (0.47)	5.47 (0.21)	6.26 (2.62)
	Pasting Temperature (°C)	80.6 (2.1)	78.7 (1.6)	76.8 (1.5)	77.3 (2.0)	77.7	77.3 (1.0)	nd
Red*	Peak Viscosity (RVU)	97 (0)	130 (21)	148 (9)	122 (8)	134 (19)	135 (10)	130 (45)
	Hot Paste Viscosity (RVU)	84 (0)	123 (17)	134 (6)	121 (8)	129 (17)	128 (6)	121 (40)
	Breakdown (RVU)	13 (0)	7 (6)	14 (7)	1 (0)	5 (4)	7 (5)	9 (11)
	Cold Paste Viscosity (RVU)	132 (0)	218 (39)	249 (13)	214 (17)	241 (32)	232 (15)	225 (80)
	Setback (RVU)	48 (0)	95 (23)	115 (12)	93 (9)	112 (19)	104 (10)	104 (42)
	Peak Time (Minute)	5.27 (0)	5.77 (0.53)	5.37 (0.36)	6.57 (0.65)	5.85 (0.65)	5.81 (0.47)	6.67 (2.74)
	Pasting Temperature (°C)	79.2 (0)	79.0 (1.8)	78.0 (0.7)	79.0 (1.3)	78.1 (1.4)	78.0 (1.3)	nd
Spanish Brown	Peak Viscosity (RVU)	126 (24)	139 (21)	153 (13)	143 (15)	150 (12)	147 (6)	141 (52)
	Hot Paste Viscosity (RVU)	121 (23)	132 (18)	143 (10)	139 (12)	144 (10)	139 (5)	134 (49)
	Breakdown (RVU)	5 (4)	6 (5)	9 (6)	5 (3)	6 (3)	8 (4)	7 (4)
	Cold Paste Viscosity (RVU)	237 (49)	235 (33)	249 (26)	253 (22)	264 (19)	250 (10)	238 (89)
	Setback (RVU)	116 (27)	102 (16)	129 (18)	114 (11)	120 (11)	116 (10)	107 (39)
	Peak Time (Minute)	6.16 (0.68)	6.03 (0.70)	5.45 (0.58)	6.19 (0.84)	5.59 (0.27)	5.68 (0.43)	5.63 (2.00)
	Pasting Temperature (°C)	79.3 (1.0)	79.5 (0.8)	77.4 (0.6)	78.2 (1.3)	78.0 (0.8)	77.8 (1.4)	nd

*Based on 1 sample in 2021; nd = not determined due to test not being performed for 5 or 10 years.

Variability in pasting characteristics were observed among cultivars (Table 26). In the green market class, the variability among cultivars was noticeable. Merrit had the lowest (90 RVU) peak viscosity in 2021, which also was the case in 2020 (114 RVU). With few exceptions, lower peak viscosities of the different cultivars were observed in samples from 2021 compared to the same cultivars in 2020. CDC Richlea and CDC Maxim-CL had the lowest hot paste (81 and 84 RVU, respectively), and cold paste (137 and 132 RVU, respectively) viscosities among the lentil cultivars. In contrast, CDC Invincible CL had the highest peak (138 RVU), hot paste (129 RVU) and cold paste (246 RVU) viscosities. Overall, lentils had pasting temperatures that were slightly higher in the 2021 harvest year compared to the same cultivar grown in 2020.

Table 26. Mean starch characteristics of lentil cultivars grown in the USA in 2021.

Market Class	Cultivar	Peak Viscosity (RVU)	Hot Paste Viscosity (RVU)	Breakdown (RVU)	Cold Paste Viscosity (RVU)	Setback (RVU)	Peak Time (Min)	Pasting Temperature (°C)
Green	Brewer	126	122	5	227	105	6.20	80.3
	CDC Greenstar*	126	125	1	240	115	5.67	81.5
	CDC Invincible CL	138	129	9	246	117	5.53	78.8
	CDC Kermit*	130	124	6	226	102	5.80	79.1
	CDC Richlea*	110	81	29	137	56	4.73	76.7
	CDC Viceroy*	128	99	29	161	63	5.13	78.4
	Merrit	90	88	3	170	82	6.93	82.5
	ND Eagle*	105	94	11	174	80	5.33	80.7
Red	CDC Maxim-CL*	97	84	13	132	48	5.27	79.2
Spanish	Morena*	123	121	2	236	116	6.93	79.3
Brown	Pardina	126	121	5	237	116	6.09	79.4

*Only one sample of cultivar tested

Faba Bean Quality Results

Sample distribution

Two faba bean samples were evaluated during the 2021 survey (Table 27). The samples were visually different both in color and size. Overall, small differences in composition were observed (Table 28). The protein content was slightly higher in the 14-24 variety than the Victus variety. The protein content was higher than protein content in chickpeas. The protein content was comparable to peas but less than the protein content of lentils. The starch content was higher for Victus compared to faba bean variety 14-24 (Table 28). Only small variability was observed for moisture and fat content while no difference in ash was found. In contrast to composition, most of the physical parameters (Tables 29) were different between the two faba bean samples. The Victus variety had a two-percentage point higher test weight compared to 14-24. Substantial differences in mean 1000 seed weight were observed. The Victus variety had a 1000 seed weight that was 2.2 times higher than that of sample 14-24. The unhydrated seeds assessment indicated that no unhydrated seed were identified. However, the seed did not visually appear to have taken up similar amounts of water compared to peas and chickpeas. This observation was most evident on the Victus variety. The water hydration capacity was only 69%, meaning that this faba bean absorbed only about 2/3 of its weight in water compared to sample 14-24 which gained nearly

Table 27. Description of dry Faba bean samples used in the 2021 pulse quality survey.

State	No. of Samples	Color	Cultivars
North Dakota	2	Black	14-24
		Brown	Victus

its entire weight in water. In contrast, the swelling capacity of the two samples were similar. Although both samples had similar swelling capacities, the Victus sample did feel harder when compressing a seed between one's fingers. The textural differences were apparent after a cooking process. The cooked firmness (Table 29) of the Victus sample was nearly two times higher than the 14-24 sample. This observation supported the subjective finger compression test. During the evaluation, the samples were prepared identically to allow for comparisons. However, modifications to cooking procedure would be warranted for the samples. The sample 14-24 had similar physical parameters to those of peas and thus a comparison to peas would be better than a comparison with the Victus sample.

Table 28. Mean proximate composition of Faba Bean cultivars grown in the USA in 2021.

		Concentration (%)				
Color	Cultivar	Moisture	Ash	Fat	Protein	Starch
Black	14-24*	8.7	3.5	1.2	24.7	38.5
Brown	Victus*	9.2	3.5	0.9	22.9	40.8

*Only one sample of each cultivar tested

Table 29. Mean physical parameters of USA Faba Bean cultivars grown in 2021.

Color	Cultivar	Test Weight (lb/bu)	1000 Seed Weight (g)	Water Hydration Capacity (%)	Unhydrated Seeds (%)	Swelling Capacity (%)	Cooked Firmness (N/g)
Black	14-24*	63.0	230	94	0	113	22.1
Brown	Victus*	64.9	504	69	0	120	42.5

*Only one sample of each cultivar tested

The color data (Table 30) supports a darker pulse where the L* value is lower than other pulses. As expected, the sample 14-24 had a lower L* value due to the black seed coat. The Victus seed color was comparable to the Spanish Brown lentils. However, only the L* value between the Spanish Brown lentils and Victus were similar. The a* values supported that green and blue contributed more to color of sample 14-24 compared to Victus, which is more red and yellow in nature. Soaking caused only small changes in the color based the color difference between the pre- and post-soaked faba beans. In general, the data on faba bean suggests similar changes to soaking as compared to other pulses. However, given that only two samples were evaluated no clear trends can be established.

With the exception of pasting temperature and breakdown, starch pasting properties differed between faba beans (Table 31). Peak and hot paste viscosity were approximately 30 RVU higher for the Victus faba beans compared to sample 14-24. In contrast, setback was significantly higher and cold paste slightly higher for the 14-24 faba bean compared to the Victus sample. Overall, the starch properties of the faba beans were comparable to the starch properties of peas, lentils and chickpeas.

Table 30. Color quality of Faba Bean cultivars grown in the USA in 2021, before and after soaking 16 hours.

		Mean Color Values*						
		Before Soaking			After Soaking			Color
Color	Cultivar	L	a	b	L	a	b	Difference
Black	14-24*	38.51	1.04	-0.54	37.10	2.02	0.35	1.93
Brown	Victus*	53.53	5.28	13.46	53.88	4.44	16.67	3.68

*Only one sample of each cultivar tested

Table 31. Mean starch characteristics of Faba Bean cultivars grown in the USA in 2021.

Color	Cultivar	Peak Viscosity (RVU)	Hot Paste Viscosity (RVU)	Breakdown (RVU)	Cold Paste Viscosity (RVU)	Setback (RVU)	Peak Time (Min)	Pasting Temperature (°C)
Black	14-24*	95	94	2	205	111	7.00	79.9
Brown	Victus*	122	120	2	194	73	6.67	79.9

*Only one sample of each cultivar tested

Chickpea Quality Results

Sample distribution

A total of 55 chickpea samples were collected from Idaho, North Dakota, and Washington between November 2021 and February 2022. Growing location, number of samples, market class, and genotype details of these dry chickpea samples are provided in Table 32. Royal (15), and Sierra (26) accounted for the majority of the chickpea evaluated.

Table 32. Description of chickpea samples used in the 2021 pulse quality survey.

State	No. of Samples	Market Class	Cultivars	
Idaho	20	Kabuli	CDC Frontier	Royal
			Sawyer	Sierra
North Dakota	4	Kabuli	CDC Frontier	CDC Orion
Washington	31	Kabuli	CDC Frontier	Dylan
			Kasin	Nash
			Pegasus	Royal
			Sierra	

Proximate composition of chickpea (Tables 33-34)

The **moisture content** of chickpeas ranged from 7.0 to 11.4% in 2021 (Table 33). The mean moisture content of the samples was 8.5%, which is lower than the 5-year mean of 9.1%. However, chickpeas grown in 2021 had the approximately the same mean moisture value as the 10-year mean moisture content (8.3%). This supports that the long-term mean moisture content of the chickpea from the region is consistent. No sample exceed the 13-14% moisture threshold for proper storage. CDC Orion had the highest moisture content at 10.3% while the Sawyer cultivar had the lowest moisture (7.0%) among all chickpea (Table 34). **Ash content** of chickpeas ranged from 2.7 to 3.6% with a mean of 3.0% (Table 28). The mean ash content of chickpeas grown in 2021 was comparable to ash contents of chickpea from the 2019 harvest year. However, the ash content was comparable to the 5- and 10-year mean value (Table 33). An unknown cultivar and CDC Frontier had the lowest ash contents at 2.8 and 2.9%, respectively, while Sawyer had the highest mean ash content at 3.6% (Table 34). The mean **fat content** was 5.6% with a range from 4.5 to 6.4% (Table 33). Literature reports indicate that chickpea has a fat content between 2 and 7%; therefore, the fat content of chickpeas grown in 2021 fall within the range reported by others but less than the fat content recorded in previous years except for chickpeas from 2019. Fat content has just recently been added to the quality survey and thus no 5- or 10-year mean values are available. The CDC Orion cultivar had the highest (6.0%) fat contents among Kabuli chickpeas (Table 34). Nash and Sawyer both had the lowest (5.0%).

Protein content of chickpeas ranged from 17.1 to 25.7%, with a mean of 19.8% (Table 33). The mean protein content of chickpea grown in 2021 was the same as the 5-year mean protein content and only slightly less than the 10-year mean protein content of 20.1%. Nash had the lowest (18.6%) protein content while Sawyer had the highest protein content at 23.5% (Table 34). **Total starch content** of chickpea ranged from 38.2 to 44.6%, with a mean of 40.7% (Table 33). The mean total starch content of chickpeas grown in 2021 was similar to the mean starch content observed in chickpea from the 2019 harvest year and was slightly higher than the 5-year mean of 40.3%. However, the starch content was lower than the 10-year mean value (42.9%). The Dylan cultivar had the lowest (38.2%) starch content while the highest (41.3%) was observed in CDC Frontier cultivar.

Table 33. Proximate composition of Kabuli chickpeas grown in the USA, 2017-2021 and corresponding long-term means.

Proximate	2021		2020	2019	2018	2017	5-year	10-year
Composition*	Range	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Moisture (%)	7.0-11.4	8.5 (0.9)	7.9 (1.1)	11.6 (2.6)	8.8 (0.9)	8.5 (0.9)	9.1 (1.4)	8.3 (2.3)
Ash (%)	2.7-3.6	3.0 (0.2)	3.0 (0.6)	2.6 (0.2)	2.8 (0.2)	2.8 (0.3)	2.8 (0.1)	2.8 (0.1)
Fat (%)	4.5-6.4	5.6 (0.3)	5.4 (0.6)	6.1 (0.5)	7.2 (1.1)	6.0 (0.4)	nd	nd
Protein (%)	17.1-25.7	19.8 (1.5)	21.1 (2.0)	19.4 (1.9)	20.8 (2.3)	19.5 (2.0)	19.8 (1.1)	20.1 (1.0)
Starch (%)	38.2-44.6	40.7 (1.3)	40.8 (3.6)	40.1 (1.8)	41.1 (2.5)	39.6 (2.0)	40.3 (0.6)	42.9 (4.7)

*Composition is on an "as is" basis; nd = not determined due to test not being performed for 5 or 10 years.

Physical parameters of chickpeas (Tables 35-38)

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 58.2 to 66.5 lbs./Bu with a mean of 61.2 lbs./Bu. This mean value is approximately the same as both the 5- and 10-year mean test weight (Table 35). The data supports the uniformity in test weight over the long-term. The test weights of individual cultivars ranged from 58.2 lbs./Bu in Dylan to 65.3 lbs./Bu in the Kasin cultivars. Dylan and Kasin also had the lowest and highest test weights in 2020, respectively. (Table 36). The range and mean **1000 seed weight** of chickpeas grown in 2021 were 294-578 g and 464 g, respectively (Table 35). The mean 1000 seed weight was greater than the 5-year and 10-year mean of 420 and 412 g, respectively. The Pegasus cultivar had a highest 1000 seed weight at 578 g while the Kasin cultivar had the lowest value at 329 g (Table 36).

Table 34. Mean proximate composition of chickpea cultivars grown in the USA, 2021.

Market Class	Cultivar	Concentration (%)				
		Moisture	Ash	Fat	Protein	Starch
Kabuli	CDC Frontier	9.1	2.9	5.6	19.4	41.3
	CDC Orion	10.3	3.0	6.0	19.7	40.5
	Dylan*	9.1	3.1	5.2	20.4	38.2
	Kasin*	8.8	3.0	5.9	19.1	40.3
	Nash*	9.6	3.1	5.0	18.6	40.2
	Pegasus*	7.8	3.0	5.9	20.2	40.9
	Royal*	8.6	3.0	5.3	20.1	41.0
	Sawyer*	7.0	3.6	5.0	23.5	40.3
	Sierra	8.2	3.1	5.8	19.7	40.6
	Unknown	10.2	2.8	5.4	19.9	40.8

* Value from only one sample.

Water hydration capacity of chickpeas ranged from 88 to 141%, with a mean of 105% (Table 35). The water hydration capacity of chickpeas from 2021 was essentially the same as the 5-year and 10-year mean value of 105%. Differences in water hydration capacities among cultivars was observed. Among Kabuli chickpea, the Sawyer cultivar had the highest water hydration capacity (131%) while CDC Orion had the lowest (92%) (Table 36). Furthermore, most of the samples had water hydration capacities in the range of 100 to 109%.

Table 35. Physical parameters of Kabuli chickpeas grown in the USA, 2017-2021 and corresponding long-term mean.

Physical Parameter	2021		2020	2019	2018	2017	5-year	10-year
	Range	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Test Weight (lb/Bu)	58.2-66.5	61.2(1.8)	61.6 (1.5)	61.0 (1.0)	62.0 (1.4)	61 (2)	61.3 (0.5)	61.2 (0.6)
1000 Seed Wt	294-578	464 (67)	417 (71)	444 (74)	410 (71)	421 (72)	420 (14)	412 (22)
Water Hydration Capacity (%)	88-141	105 (9)	108 (8)	102 (8)	102 (10)	104 (13)	104 (2)	105 (4)
Unhydrated Seeds (%)	0-1	0 (0)	0 (0)	0 (0)	0 (2)	0 (1)	0 (0)	1 (1)
Swelling Capacity (%)	113-228	144 (20)	145 (17)	138 (15)	130 (14)	129 (27)	137 (7)	nd
Cooked Firmness (N/g)	15.1-66.5	19.7 (2.3)	19.6 (2.9)	20.7 (3.8)	27.9 (6.1)	26 (5)	23.2 (3.5)	nd
% of Sample Retained on 22/64 Sieve	2.8-96.6	69.0 (21.5)	55.6 (26.5)	64.2 (28.3)	*	*	nd	nd
% of Sample Retained on 20/64 Sieve	3.0-56.4	22.8 (12.6)	34.3 (18.6)	29.1 (20.8)	*	*	nd	nd
% of Sample Retained on 18/64 Sieve	0.4-55.6	7.1 (9.9)	9.7 (12.4)	6.1 (10.0)	*	*	nd	nd
% of Sample Passed Through an 18/64 Sieve	0.0-12.8	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.

The **unhydrated seed percentage** was 0% for most chickpeas. The 0% unhydrated seeds matched the 5- and 10-year mean values of 0 and 1%, respectively (Table 35). All of the cultivars except Sawyer had 0% mean unhydrated seed values (Table 36). However, no issues were observed with the rehydration of the chickpea samples. The **swelling capacity** of chickpeas ranged from 113 to 228%, with a mean value of 145% (Table 35). The mean swelling capacity value of chickpea from 2021 was comparable to chickpea from 2020 but higher than the previous five years (2015-2019) and the 5-year mean of 137%. An unknown cultivar and Sawyer cultivar had the greatest mean swelling capacity while the CDC Orion cultivar had the lowest values among chickpeas (Table 36). The swelling capacity of CDC Frontier cultivar has been evaluated since 2014. The swelling capacity of 105% (2014), 116% (2016), 130% (2020), 131% (2021), 134% (2018), 136% (2017, 2019) and 138% (2015) were observed over the 8-year period. The results show a consistent value over the last several years. The **cooked firmness** of all chickpea ranged from 15.1 to 66.5 N/g, with a mean value of 19.7 N/g (Table 35). The mean firmness value for chickpea in 2021 matched the value from the chickpea grown in 2020 and was less than the 5-year mean value (23.2 N/g). This supports chickpea were less firm after cooking compared to chickpea from previous years. Among the cultivars, Sawyer had the lowest cooked firmness (17.0 N/g) while and unknown cultivar (23.1 N/g) and Royal (21.3 N/g) cultivars were the firmest (Table 36). The Sawyer cultivar had the highest water hydration and

Table 36. Mean physical properties of chickpea cultivars grown in the USA, 2021.

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	61.8	373	100	0	131	18.5	48.2	41.7	9.5	0.6
CDC Orion	63.1	375	92	0	113	20.9	44.0	42.0	13.0	1.0
Dylan*	58.2	502	109	0	149	19.6	84.4	13.4	2.2	0.0
Kasin*	65.3	329	107	0	149	18.6	10.0	56.4	33.2	0.4
Nash*	61.3	549	95	0	131	18.6	43.2	47.6	7.6	1.6
Pegasus*	61.6	578	113	0	147	19.5	96.6	3.0	0.4	0.0
Royal*	62.3	510	112	0	161	21.3	75.4	18.3	5.2	1.1
Sawyer*	61.9	312	131	1	174	17.0	33.2	29.6	26.8	10.4
Sierra	60.0	472	101	0	134	18.9	77.0	18.0	4.3	0.7
Unknown	64.5	348	103	0	180	23.1	29.7	35.0	30.4	4.9

* Value from only one sample.

swelling capacities and the lowest cooked firmness supporting the inverse relationship between ability to hydrate and firmness. **Retention** of chickpea on a series of sieves was used to determine chickpea size. This was the third year of this test. The mean retentions of 69.0, 22.8, 7.1, and 1.1% on the 22/64, 20/64, 18/ 64 and passed through the 18/64-inch sieves were observed in the 2021 chickpea, respectively (Table 30). The range of retention on the largest screen (22/64-inch sieve) was from 2.8 to 96.6%. The percentage of retention of chickpeas on the two largest screens (22/64 and 20/64-inch sieve) was approximately 92% in 2021 while retention values of 90 and 93% were observed for the chickpea harvested in 2020 and 2019, respectively. The highest percentage retention of the samples on the 22/64-inch sieve was observed for the Pegasus (97%) while the lowest (33%) retention on the 22/64-inch sieve was observed in Sawyer (Table 36).

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 37). **Color quality** indicated that the lightness (i.e., L*) of the chickpeas from 2021 was generally higher than previous years (Table 37). In 2021, the a* value of 6.31 was most similar to the a* value of chickpea from 2020. The b* value for chickpeas from 2021 indicated similar yellowness to the chickpea from 2020, a less yellow color compared to chickpea samples from 2015 to 2018, including the 5- and 10-year mean yellowness, but more yellow than chickpea from 2019. The color of the chickpeas changed after the soaking process. Similar to peas and lentils, chickpea became lighter as evidenced by the higher L* values (Table 37) 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. In contrast, chickpeas from all years became yellower (i.e., increased b* value) after soaking. The color difference between the pre- and post-soaked chickpea from 2021 was most similar to the color difference for samples from 2020 but higher than in chickpea from 2019 and lower than in chickpea from 2017-2018 and the 5-year b* value (Table 37).

Table 37. Color quality of chickpeas grown in the USA before and after soaking, 2018-2021 and corresponding means.

	Mean (SD) Color Values					
	Before Soaking					
Color Scale*	2021	2020	2019	2018	5-Year Mean	10-Year Mean
L* (lightness)	61.33 (1.25)	60.47 (1.43)	55.69 (1.73)	55.01 (2.38)	55.52 (2.97)	61.09 (8.84)
a* (red-green)	6.31 (3.73)	6.07 (1.60)	5.17 (0.61)	8.55 (1.43)	7.59 (4.75)	7.59 (2.00)
b* (yellow-blue)	14.41 (2.07)	15.49 (1.37)	10.95 (0.80)	21.28 (1.99)	18.12 (4.75)	18.89 (5.30)
	After Soaking					
Color Scale*	2021	2020	2019	2018	5-Year Mean	10-Year Mean
L* (lightness)	61.79 (0.68)	61.39 (0.72)	56.16 (1.07)	56.68 (1.68)	57.41 (2.31)	63.21 (10.69)
a* (red-green)	6.69 (0.52)	6.41 (1.71)	5.21 (0.42)	11.35 (1.05)	9.05 (3.00)	8.80 (2.82)
b* (yellow-blue)	24.81 (1.68)	25.78 (1.72)	16.99 (6.41)	34.94 (2.20)	29.24 (7.82)	31.77 (9.79)
Color Difference	11.23 (3.35)	10.47 (1.79)	6.41 (1.13)	13.69 (1.96)	13.91 (6.99)	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 is the change in color after soaking. nd = not determined due to test not being performed for 10 years.

Among cultivars, Dylan had the highest L* value (64.03) while Kasin had the lowest (i.e., 58.09). The Dylan cultivar also had the highest L* value among chickpea cultivars in 2018, 2019 and 2020. The Kasin cultivar also had the lowest L* in 2020. Dylan had the lowest a* value among cultivars. The highest yellowness value (i.e., b*) was observed in Royal (Table 38). Visual observations support the color value differences as the Dylan cultivar appeared whiter in color than other cultivars. Most, but not all, cultivars 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 Kasin cultivar (Table 38) while the Sierra cultivar had the least color change. The change in color observed in the Kasin cultivar was likely due to the significant increase in yellowness (a change in b* values) during the soaking. This was supported by visual observations where the Kasin cultivar appeared more yellow after soaking.

Table 38. Mean color quality of chickpea cultivars grown in the USA, 2021.

		Mean Color Values**						
Market		Before Soaking			After Soaking			Color
Class	Cultivar	L	a	b	L	a	b	Difference
Kabuli	CDC Frontier	60.22	6.74	15.09	61.94	7.34	27.82	12.88
	CDC Orion	59.72	6.65	15.63	61.78	7.24	26.65	11.23
	Dylan*	64.03	4.44	12.80	62.29	5.94	23.67	11.18
	Kasin*	58.09	6.73	14.19	62.94	7.30	29.04	15.64
	Nash*	62.80	5.71	14.19	62.30	6.52	25.38	11.24
	Pegasus*	61.91	6.03	14.72	61.27	7.08	24.94	10.33
	Royal*	60.78	7.79	13.95	61.49	7.06	24.94	12.52
	Sawyer*	58.14	5.95	13.66	59.91	6.54	24.71	11.21
	Sierra	62.06	5.48	14.67	61.86	6.25	23.64	9.72
	Unknown	60.82	5.83	12.98	62.71	7.55	27.26	14.55

* Value from only one sample. **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.

Pasting properties (Tables 39-40)

Peak and hot paste viscosities of chickpeas grown in 2021 were similar to values for chickpea from 2017 and 2018 but lower than the mean 5- and 10-year viscosity values (Table 39). The cold paste viscosity of the 2021 chickpea crop was most similar to the chickpeas from 2019 and the mean 5- and 10-year cold paste viscosity values. The peak time was slightly longer for samples from 2021 compared to other crop years but was lower than the mean 10-year value. The pasting temperature was higher for the chickpeas from 2021, except 2019, compared to chickpeas from other years and to the 5-year mean pasting temperature. Among chickpeas, Kasin and Nash had the lowest peak viscosity (120 RVU) while Sawyer (157 RVU) had the highest peak viscosity (Table 40). These same cultivars had the lowest (Kasin and Nash) and highest (Sawyer) hot paste viscosities. The lowest and highest cold paste viscosities were observed in Pegasus (225 RVU) and Royal (224 RVU) and CDC Orion (159 RVU), respectively. Pasting temperature was lowest (75.8 °C) and highest (79.2 °C) for Kasin and Sawyer cultivars, respectively.

Table 39. Starch characteristics of Kabuli chickpeas grown in the USA, 2017-2020 and corresponding long-term means.

Starch	2021		2020	2019	2018	2017	5-year	10-year
Characteristic	Range	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Peak Viscosity (RVU)	100-202	129 (20)	136 (16)	136 (18)	131 (15)	126 (15)	135 (3)	138 (17)
Hot Paste Viscosity (RVU)	97-181	123 (18)	128 (13)	131 (16)	125 (12)	124 (14)	129 (3)	130 (12)
Breakdown (RVU)	8-15	10 (1)	7 (5)	5 (4)	6 (6)	3 (2)	6 (1)	8 (6)
Cold Paste Viscosity (RVU)	136-417	200 (53)	186 (23)	198 (30)	187 (29)	185 (24)	196 (11)	203 (37)
Setback (RVU)	36-241	77 (36)	58 (15)	68 (18)	62 (20)	62 (13)	67 (8)	67 (31)
Peak Time (Minute)	4.80-7.00	6.47 (0.63)	6.12 (0.56)	6.33 (0.57)	6.06 (0.65)	6 (0)	6.18 (0.15)	7.01 (1.76)
Pasting Temperature (°C)	75.0-81.4	76.9 (1.2)	78.0 (1.4)	75.6 (1.6)	75.8 (1.9)	76 (2)	75.8 (1.3)	nd

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

Table 40. Mean starch characteristics of chickpea cultivars grown in the USA, 2021.

Market Class	Cultivar	Peak Viscosity (RVU)	Hot Paste Viscosity (RVU)	Breakdown (RVU)	Cold Paste Viscosity (RVU)	Setback (RVU)	Peak Time (Min)	Pasting Temperature (°C)
Kabuli	CDC Frontier	125	122	10	189	67	6.71	77.1
	CDC Orion	123	119	10	159	39	6.33	78.4
	Dylan*	121	119	10	174	56	6.07	78.4
	Kasin*	120	118	10	175	57	6.27	75.8
	Nash*	120	118	10	186	68	7.00	79.1
	Pegasus*	135	131	11	225	93	6.27	77.6
	Royal*	142	132	11	224	92	5.73	76.7
	Sawyer*	157	142	12	205	63	5.47	79.2
	Sierra	122	119	10	195	76	6.98	76.7
	Unknown	132	112	9	161	49	5.44	75.9

* Value from only one sample.

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 41-43)

The mean **water hydration capacity** of canned peas was 143% for all peas (Table 41). This value was lower than the water hydration capacity of peas from the 2017-2020 crop years. A difference in water hydration capacity between the green (137%) and yellow (162%) market classes was observed. Furthermore, Winter (123%) also had lower water hydration capacities compared to previous crop years (Table 41). Water hydration capacities ranged from 109 to 196 for all peas in 2021 while the range in 2020 was 104 to 265% for all peas. Overall, the data indicates less swelling of the peas in 2021. In green peas, Scotch and Ariel had comparable water hydration capacity at 122% while Arcadia had the highest at 161%. In yellow cultivars, AAC Chrome and Spider had the highest (196 and 193%, respectively) mean water hydration capacities while the Pizzaz had the lowest (118%) value (Table 43). The winter peas generally had similar water hydration capacities (121-132%) compared to the green and yellow peas. The results of the soak test did not directly translate into similar results in the canning water hydration in the context of an order for the cultivars except in the case of the winter peas.

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 156 to 201%, with a mean value of 181% (Table 41). These values were lower than the water hydration capacity of peas from the 2017-2020 crop years. In contrast to water hydration capacity, mean swelling capacity values for the green, yellow and winter peas were comparable (180-182%). The green pea cultivars Ginny and Columbian had the lowest (163%) and highest (196%) mean swelling capacities, respectively. In yellow cultivars, AAC Chrome and Spider had the highest (197 and 195%, respectively) mean swelling capacities while an unknown cultivar had the lowest swelling capacity at 166% (Table 43). The mean swelling capacity of Vail was lower than the other winter peas. Different cultivars accounted for the upper and lower swelling capacities between the canning and soak tests.

The **canned firmness** values of peas were not significantly lower than the cooked firmness values of soaked peas. For comparison, the mean cooked firmness for all peas from 2021 was 24.0 N/g (Table 7). This was not anticipated since the canning involves higher temperatures followed by a room temperature equilibrium time of 3 weeks before firmness can be evaluated. The mean canned firmness value of all peas was 17.8 N/g (Table 41). This was higher than the firmness values observed in the 2017-2020 canned peas. In general, winter peas had the highest (23.7 N/g) and yellow peas the lowest (12.6 N/g) canned firmness.

Arcadia (14.9 N/g) cultivar had the least firmness among the green peas while Ariel (24.9 N/g) was the firmest (Table 43). In yellow peas, AAC Chrome and Spider had the least (5.6 and 6.0 N/g) firmness while Pizzaz had the greatest (22.3 N/g) firmness among yellow cultivars. These three cultivars also had the highest (AAC Chrome and Spider) and least (Pizzaz) water hydration capacities an demonstrate the reverse association between hydration capacity and cook firmness.

Table 41. Mean physical parameters of canned dry pea grown in 2017-2021.

Physical Parameter	2021 Range	2021 Mean (SD)	2020 Mean (SD)	2019 Mean (SD)	2018 Mean (SD)	2017 Mean (SD)
All Pea Samples						
Water Hydration Capacity (%)	109-196	143 (28)	199 (30)	260 (46)	214 (36)	210 (27)
Swelling Capacity (%)	156-201	181 (12)	205 (19)	204 (24)	214 (18)	204 (23)
Canned Firmness (N/g)	5.6-29.7	17.8 (7.6)	7.3 (3.0)	5.9 (2.3)	4.7 (1.3)	5.3 (2.0)
Green Pea Samples						
Water Hydration Capacity (%)	120-182	137 (21)	198 (32)	254 (45)	193 (26)	210 (30)
Swelling Capacity (%)	163-196	180 (11)	204 (20)	200 (20)	206 (30)	200 (23)
Canned Firmness (N/g)	6.6-29.7	19.0 (6.7)	7.2 (3.1)	6.35 (2.31)	5.2 (1.0)	5.0 (1.4)
Yellow Pea Samples						
Water Hydration Capacity (%)	113-196	162 (29)	199 (28)	265 (46)	227 (36)	210 (24)
Swelling Capacity (%)	156-201	182 (14)	206 (20)	206 (25)	216 (17)	207 (23)
Canned Firmness (N/g)	5.6-25.1	12.6 (6.7)	7.4 (3.0)	5.73 (2.21)	4.4 (1.4)	5.5 (2.4)
Winter Pea Samples						
Water Hydration Capacity (%)	109-137	123 (8)	217 (23)	214 (41)	*	*
Swelling Capacity (%)	164-196	180 (12)	211 (6)	204 (16)	*	*
Canned Firmness (N/g)	17.0-28.4	23.7 (3.6)	7.3 (2.4)	7.39 (4.28)	*	*

*Canning quality not determined on winter pea prior to 2019.

The color of the dry pea changed after the canning process. The color difference fell between 10.40 and 11.95 for all peas with winter having the lowest color difference. With the exception of 2019, the color difference in difference between the dry and canned peas was less than previous crop years (Table 42). The lightness decreased during canning for all market classes. In the soak test, only the green cultivars darkened upon soaking (Tables 10). The greatest color difference was observed in the Ariel (green) and Durwood (yellow) cultivars after canning (Table 43) while the Shamrock (green) and Cronos (yellow) cultivars had the lowest color difference. Shamrock also had the lowest color change in the 2019 and 2020 canning evaluation.

Table 42. Mean color characteristics of canned dry pea grown in 2017-2021.

	Mean (SD) Color Values*						
	Before Canning			After Canning			
Sample	L	a	b	L	a	b	Color Difference
Green Pea Samples							
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)
2018	51.68 (3.57)	-1.92 (0.77)	14.15 (1.49)	46.02 (2.61)	2.38 (0.54)	30.58 (2.12)	18.16 (1.93)
2017	52.84 (2.73)	-1.26 (1.17)	15.13 (1.54)	46.20 (3.07)	2.45 (0.59)	29.15 (1.96)	16.61 (2.12)
Yellow Pea Samples							
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 (125)	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)
2018	58.76 (2.39)	6.91 (0.99)	17.33 (1.53)	56.91 (3.94)	6.59 (1.13)	30.96 (3.65)	13.30 (4.68)
2017	58.52 (2.32)	6.71 (1.66)	20.29 (2.09)	54.73 (2.30)	6.22 (1.25)	29.65 (3.19)	11.03 (3.20)
Winter Pea Samples**							
2021	54.94 (1.26)	-1.73 (1.93)	9.47 (2.26)	46.21 (2.74)	0.82 (1.33)	14.19 (2.72)	10.40 (1.33)
2020	56.18 (1.96)	-0.87 (2.00)	10.34 (2.87)	52.02 (1.91)	-1.24 (3.31)	21.53 (1.17)	12.07 (3.08)
2019	46.22 (3.64)	-0.59 (1.91)	4.92 (1.36)	40.09 (5.14)	1.73 (3.05)	8.22 (3.94)	7.83 (0.85)

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. **Canning quality not determined on winter pea prior to 2019.

Table 43. Mean physical and color parameters of canned dry pea cultivars grown in 2021.

					Mean Color Values*						
					Before Soaking			After Soaking			
Market Class	Cultivar	Hydration Capacity (%)	Swelling Capacity (%)	Canned Firmness (N/g)	L*	a*	b*	L*	a*	b*	Color Difference
Green	Arcadia	161	178	14.9	59.60	-1.28	10.23	50.04	0.54	16.04	11.43
	Ariel**	122	175	24.9	59.10	-2.16	8.93	46.21	0.78	12.29	13.65
	Columbian**	129	196	21.3	59.16	-2.61	11.57	46.95	0.16	13.64	12.68
	Ginny**	130	163	22.2	59.63	-2.04	10.08	48.88	0.74	14.67	12.02
	Scotch	121	173	23.3	56.65	-1.63	11.38	47.31	-0.02	14.01	9.86
	Shamrock	135	187	17.1	54.50	-3.42	10.35	47.39	0.16	14.33	8.93
Yellow	AAC Chrome**	196	197	5.6	64.64	5.34	15.24	57.95	6.97	24.91	11.87
	AAC Profit**	184	185	7.5	65.22	5.69	15.15	57.70	7.06	23.89	11.64
	AC Agassiz**	185	190	6.4	66.00	4.98	14.58	58.18	7.85	23.10	11.92
	CDC Inca**	163	171	11.7	64.17	5.72	15.81	56.55	8.79	25.14	12.44
	Cronos**	124	175	20.6	62.24	5.26	14.69	55.23	6.33	21.74	10.01
	Durwood	184	191	8.2	64.86	4.89	14.61	56.61	6.94	24.54	13.16
	Pizzaz**	118	171	22.3	63.66	5.95	15.40	53.98	5.78	20.68	11.06
	Salamanca	162	185	10.5	64.50	5.05	14.33	55.61	8.05	22.03	12.18
	Spider**	193	195	6.0	64.81	5.27	14.72	56.04	6.46	22.78	11.99
	Unknown	131	166	20.9	63.34	5.50	15.85	54.00	6.51	22.39	11.52
Winter	Blaze**	125	194	21.8	61.84	3.29	14.54	51.55	2.86	19.47	11.68
	Goldenwood**	132	196	17.0	57.58	0.64	13.29	51.19	4.00	19.70	9.66
	Vail	121	177	24.7	53.88	-2.54	8.49	45.06	0.24	12.99	10.35

*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.

Chickpeas (Tables 44-45)

The mean **water hydration capacity** of canned chickpea was 128% with a range from 108 to 164%. These values were comparable to the canned chickpeas from 20117 and 2018 (Table 44). The water hydration capacity of canned chickpea was higher than that observed in the soak test (105%). The CDC Orion cultivar had the lowest water hydration capacity at 109% while Sawyer had the highest at 164% (Table 45). In 2020, Sawyer also had the highest water hydration capacity. In the soak test, CDC Orion and Sawyer cultivars had the lowest and highest water hydration capacities, respectively, which closely matched the outcome of the canning results. 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 135 to 211%, with a mean value of 163%. The results of the individual cultivars mirror the water hydration capacity. The CDC Orion cultivar had the lowest swelling capacity at 135% while Sawyer had the highest at 204% (Table 45).

The **canned firmness** values of chickpeas were slightly lower than the cooked firmness values of soaked chickpeas. The mean canned firmness value of all chickpeas was 14.8 N/g (Table 44). In comparison, the mean cooked firmness for all chickpeas was 19.7 N/g (Table 35). As expected, the canned chickpeas were less firm than the cooked chickpeas. An unknown cultivar was the least firm while Kasin and Nash were the firmest (Table 45). The color of the chickpeas changed after the canning process. The color difference fell between 5.79 and 11.76, with a mean value of 9.81 for all chickpeas. The color difference was comparable to the canned chickpeas from the 2019 crop year. A higher color difference was observed in soaked (11.23) chickpeas compared to canned (9.81) chickpeas. The L* or lightness decreased during canning (Table 45). In contrast, the L* values of chickpeas generally increased in the soak test. The greatest color difference after canning was observed in the Nash cultivar while Sawyer had the least color change (Table 45). In general, the lower hydration and swelling properties and higher firmness indicate less hydration and a firmer chickpea after canning compared to chickpea from previous years.

Table 44. Mean physical and color parameters of canned chickpea grown in 2017-2021.

Year	Hydration Capacity (%)	Swelling Capacity (%)	Canned Firmness (N/g)	Mean (SD) Color Values*						
				Before Soaking			After Soaking			
				L	a	b	L	a	b	Color Difference
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)
2018	125 (11)	173 (23)	9.9 (1.8)	53.45 (3.13)	9.06 (1.14)	21.74 (1.67)	47.39 (2.23)	8.62 (3.57)	26.81 (2.32)	9.29 (4.20)
2017	123 (10)	168 (18)	10.4 (2.2)	55.02 (2.41)	8.55 (1.45)	21.28 (2.01)	45.85 (2.78)	7.91 (1.12)	24.27 (2.78)	10.49 (2.44)
2021 (Data Range)	108-164	135-211	8.5-17.0	58.55-63.92	4.68-7.15	13.01-16.08	49.94-54.30	4.72-7.77	14.30-18.10	5.79-11.76

*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 45. Mean physical and color parameters of canned dry chickpea cultivars grown in 2021.

Cultivar	Hydration Capacity (%)	Swelling Capacity (%)	Canned Firmness (N/g)	Mean Color Values*						
				Before Soaking			After Soaking			
				L	a	b	L	a	b	Color Difference
CDC Frontier	123	167	15.1	60.43	6.75	15.30	51.47	7.05	16.69	9.25
CDC Orion	109	135	15.2	60.65	6.71	16.08	51.29	7.56	16.02	9.39
Dylan**	133	174	14.5	63.92	4.68	13.18	54.30	6.02	16.71	10.34
Kasin**	128	170	15.6	60.03	7.15	15.51	52.75	5.82	17.16	7.58
Nash**	123	167	15.6	62.92	5.82	14.45	52.82	6.50	17.36	10.53
Pegasus**	135	157	15.5	61.68	5.81	14.66	52.13	6.85	15.83	9.71
Royal**	135	174	15.4	60.77	5.99	14.03	51.63	6.15	15.49	9.31
Sawyer**	164	204	12.3	58.55	5.94	13.94	54.14	6.67	17.59	5.79
Sierra	124	156	14.5	62.01	5.46	14.15	51.71	6.48	15.24	10.49
Unknown	127	165	11.9	60.76	6.73	15.60	51.63	5.38	15.91	9.29

*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. **Only one sample of cultivar tested.

Author

Dr. Clifford Hall, Professor, Pulse Quality, Dairy and Food Science, South Dakota State University, P.O. Box 2104, Brookings, SD, USA 56007.

Pulse Quality Technical Team

Graduate Students: **Abdulmalik Albu Tuwaybah, Hussain AL Naser, Sushmita Karki, Shirin Kazemzadehpournaki**

Undergraduate lab researchers: **Jessica Christoffer**, **Dana Edleman**, **Jeffrey Lehman**

Funding Support

- Northern Pulse Growers Association
- U.S. Dry Pea and Lentil Council
- South Dakota State University Agriculture Experimental Station

Acknowledgements

The 2021 U.S. Pulse Quality team acknowledges support received from funding sources, and Andrea Schubloom for assistance creating the print version of the report. Please direct questions, comments, suggestions, or requests for copies of this report to:

Dr. Clifford Hall (clifford.hall@sdstate.edu) at South Dakota State University,
Ms. Shannon Berndt (berndt@northernpulse.com) at Northern Pulse Growers Association, and
Mr. Todd Scholz (tscholz@usapulses.org) at the USA Dry Pea and Lentil Council.

Research Corner

The project below was an outcome of research completed by Dana Edleman and Clifford Hall. The basis for this research is the development of an aquafaba that is more easily handled and more shelf stable than handling and storage of liquid Aquafaba. Hummus is a common use of whole chickpeas, which requires a cooking step in excess water. The liquid remaining after cooking chickpeas is referred to as aquafaba or is the liquid isolated from canned chickpea. Aquafaba has the unique ability to foam like whipped egg whites and is a waste product that is underutilized by the food industry. The high volume of water is an obstacle to fully utilize this waste product. Thus, the goal of this research was to concentrate the solids by reverse osmosis followed by drying. Furthermore, foaming potential and quality were evaluated. Dried aquafaba was prepared by cooking chickpea in excess water. After removal of the chickpea, the liquid aquafaba (3% solids) was subjected to reverse osmosis to concentrate the solid. The concentrated aquafaba (13% solids) was then subjected to freeze, tray, and spray drying. Total solid percentage of the aquafaba samples were measured at the cooking stage, after reverse osmosis, and after drying. Total solids achieved during the cooking stage was 3.3%, after reverse osmosis the total solids increased to 12.9%. After drying, total solids reached 90.3, 91.8, and 95.0% for tray-, freeze-, and spray-dried samples, respectively. Differences in the appearance of the dry product were observed (Figure 1). However, color differences were not as apparent once the samples were re-hydrated. Based on preliminary foaming results with lab prepared aquafaba, concentrations of 4, 6, 8, and 13% were identified for rehydration and use in the foaming evaluation (Figure 1).

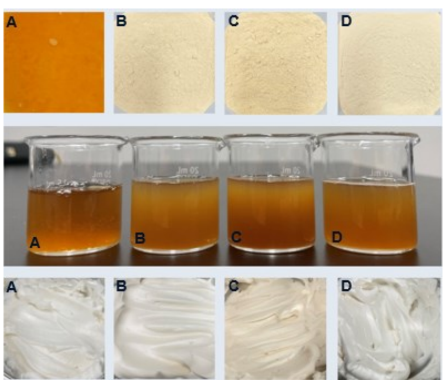
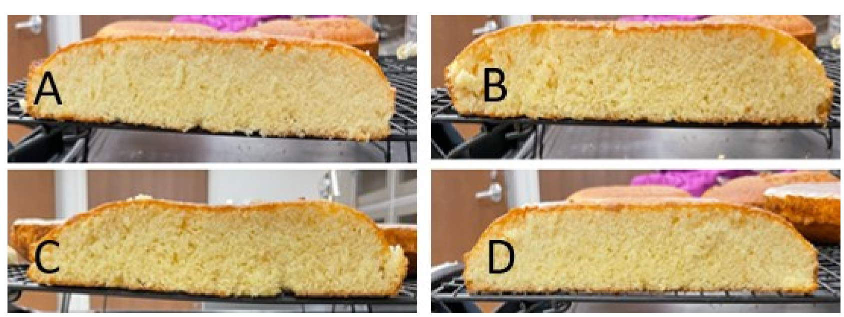


Figure 1. Dried aquafaba (top), rehydrated aquafaba (middle), and foam (bottom) of aquafaba having 13% solids. Aquafaba obtained by reverse osmosis (A), freeze drying (B), tray drying (C), and spray drying (D).

The density, viscosity, and foam capacity and stability were measured on the aquafaba that was rehydrated at concentrations of 4, 6, 8, and 13%, and compared to a reverse osmosis retentate that did not undergo drying (i.e., control). The color of the of the dried were similar, but the tray dried sample was slightly darker than the freeze- and spray-dried aquafaba. Viscosity of the liquid aquafaba increased as the concentration increased. However, only the viscosity of the 13% aquafaba solution was significantly different among samples. Overall, the 8% aquafaba concentration had the highest foam capacity and stability compared to the other concentrations, regardless of drying method. However, cakes made with 8% aquafaba resulted in cakes that had deflated centers. Reducing the aquafaba to 6% resulted in cakes that had a shape similar o the egg containing cakes. Overall, the cakes made with the dried aquafaba, except tray dried aquafaba, produced uniform structure (Figure 2).

Reverse osmosis proved to be an effective method to remove significant amounts of water from the original aquafaba. In addition, the foaming data supports that liquid (non-dried) aquafaba had the best foaming capacity and stability. However, cake made with any of the aquafaba samples had better moistness compared to the product containing egg.

Figure 2. Cake cross sections for yellow cakes made with 6% aquafaba solution, where aquafaba was obtained by A = reverse osmosis, B = freeze drying, C = tray drying, and D = spray drying. compared to E, a control made with egg.



SOUTH DAKOTA
STATE UNIVERSITY

College *of* Agriculture, *Food and Environmental Sciences*

USA Dry Pea & Lentil Council

Northern Pulse Growers Association