NITROGEN AND SPACING REQUIRMENTS FOR ADVANCED CHIPPING SELECTIONS ND7799C-1 AND ND7519-1

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

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ABSTRACT

To understand the best agronomic practices, including nitrogen fertilization rate and within-row spacing for two potential cultivar releases of NDSU, a study was carried out in 2018 and 2019 for the advanced chipping selections ND7799c-1 and ND7519-1. Measurements included nitrogen uptake efficiency, specific gravity, Hunter L value, glucose and sucrose contents. Results indicated that ND7799c-1 grown at 23 cm within-row spacing had a similar marketable yield to an industry standard, Dakota Pearl in 2018. ND7519-1 yielded similarly to Dakota Pearl. Nitrogen was not a significant variable impacting yield or chipping quality in 2018 or 2019. Both advanced selections had lower sucrose and glucose levels at the time of harvest compared to Dakota Pearl. ND7799c-1 could be stored for 8 months, and ND7519-1 could be stored 6-8 months before chip quality decreased. Implications from the research show that ND7799c-1 and ND7519-1 could be successful in the Northern Plains production area.

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To Dr. Andy Robinson, who took a chance on me and gave both me and my wife and children a opportunity to come to NDSU and start down a new career path, which hopefully I will not only be able to bless our own lives but the lives of all of God's children.

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DEDICATION

To my sweet wife and best friend, and two little tuber lovers Jesse and Lizzy

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LIST OF ABBREVIATIONS

N...Nitrogen

NUE ....Nitrogen Uptake Efficiency

SNAC...Snacking Nutrition And Convenience

ESN ....Environmentally Smart Nitrogen

1. LITERATURE REVIEW

1.1. Growth and Development

Potato plant growth and development can be separated into five distinct phases: sprouting, vegetative growth, tuber initiation, tuber bulking, and maturation (Dwelle, 2003). Potato is vegetatively propagated, and genetically identical daughter tubers are used to plant subsequent generations. Daughter tubers are metabolically active at harvest, but have strong endodormancy that prohibits sprouting (Dwelle, 2003). This endodormancy is controlled by hormones, yet the length and depth of this dormancy depends on the cultivar and environmental factors occurring during tuber development and storage, as well as stress during and after harvest. When the tuber begins to lose its strong endodormancy, sprouting begins. The apical bud of the tuber becomes dominant and inhibits the growth of other buds, eventually this dominance weakens and allows for the sprouting of multiple axillary buds (Sonnewald and Sonnewald, 2014).

The second growth stage of potato plant growth occurs when the shoots and roots develop. The shoots will elongate until exposed to light, and once exposed to light the stems will form leaves. The underground shoots, never exposed to light, will form stolons. The timing of leaf onset, canopy production, and row closure widely depends on the potato cultivar. Short season cultivars put more energy into shoot than root development, allowing for earlier tuber initiation; however, long season cultivars delay tuber initiation by focusing energy early into more vigorous root and shoot development (Dwelle, 2003).

The third growth stage is tuber initiation. The stolons underground begin to hook at the tips and swell. This modified stem will form the tuber and act as a sink for deposition of starch, sugars, water and other nutrients produced or acquired by the plant. In cultivars such as Russet

Burbank, this occurs earlier during flowering (Dwelle, 2003). Hooking timing varies by cultivar. Tuber initiation is controlled by a hormone ratio of gibberellic acid and abscisic acid (Xu et al., 1998). The plants shift their resources from vine growth to tuber growth when there is a reduction of gibberellic acid and an increase in abscisic acid. Environmental factors can also affect the timing of tuber initiation; excessive nitrogen rates, or hot nighttime soil temperatures will delay tuber initiation, while water or nitrogen stress might result in earlier tuber initiation (Walworth and Carling, 2002). Not all tubers that initiate will make it to maturity. If too high of drought or heat stress are present, some of the tubers that have begun to form will be reabsorbed and the plant will repurpose the stored water, and carbohydrates for other plant processes (Walworth & Carling, 2002).

During the tuber bulking phase, the daughter tubers swell with water, starch, and sugars (Dwelle, 2003). The overall yield produced by the potato crop is dependent on the length of the tuber bulking period and both the leaf canopy’s photosynthetic activity and its duration. The length of the tuber bulking period is highly variable depending on the cultivar (long or short seasoned), temperature, fertilization, physiological age of the seed, within-row spacing, pest management, and the original planting date (Dwelle, 2003). During the tuber bulking period, consistent temperatures, moisture, and nutrients allow for optimal growth, while defoliation due to insects, disease, hail, or any factors that would harm the foliage, will shift the plants resources from the tuber to repairing the canopy.

The final phase of growth is tuber maturity, and it is when vine senescence occurs and the skin on the tuber, the periderm, thickens preventing moisture loss and providing defense against pathogens (Halderson and Henning, 1993). Timing of nitrogen applications plays a key role in skin development. During the maturation phase, total dry matter accumulation in the tuber increases helping to raise the specific gravity, which is an indirect measure of dry matter content (Iritani and Weller, 1980). Sugars are converted to starch allowing for better processing and storage (Iritani and Weller, 1980).

1.2. Nitrogen and Nitrogen Management

Nitrogen is often considered the most important macro nutrient that plants require. Nitrogen affects the formation of enzymes, proteins, nucleic acids and free amino acid in the plant (Yadav et al., 2017). Nitrogen also plays an important role in photosynthesis in the function and formation of enzymes, as well as being a crucial component in the structure of chlorophyll. The central ring of the chlorophyll molecule itself is made up of four nitrogen atoms, surrounding a magnesium. Thus, a common sign of nitrogen deficiency in plants is yellowing of the older leaves, due to degradation of the chlorophyll molecules and translocation of nitrogen to younger tissue.

Although nitrogen is important for the potato plants, providing the correct amount is essential for maximum returns. However, the correct amount of nitrogen needed to produce the highest yield varies depending on cultivar and environment. Providing more nitrogen than the plant requires can delay tuber initiation and bulking, instead devoting the plant's energy into vine growth (Boydston et al., 2017). Another problem with excess nitrogen is simply an economic loss to the farmer. Excess nitrogen can also lead to a lower specific gravity by leading to greater vine and root growth, and delaying tuber initiation, bulking and maturation; this effect is more important when producing cultivars with that are earlier maturing and better suited for a shorter growing seasons. Excess nitrogen can also accumulate in the tubers as soluble nitrogen compounds that can impact specific gravity (Dwelle, 2003). Additionally, excessive nitrogen can delay tuber maturity, minimize russeting, and delay vine senescence. Harvesting of inmature tubers can lead to excessive bruising due to the green vines getting caught in the harvester, or failure of the tubers to successfully detach from the stolons. Problems at harvest can lead to losses of yield, quality, and economic returns. Excessive nitrogen can also affect tuber quality by causing defects such as hollow heart or brown center at tuber initiation (Olsen, et al., 2003). Fluctuations in nitrogen availability can lead to knobby, misshapen tubers, growth cracks, or feathering and skinning. However, insufficient nitrogen can inhibit plant shoot growth and early tuber initiation can be caused by low nitrogen rates, especially early in the season, mid- to late-April (Kelling, et al., 2015). Insufficient nitrogen (N) can also lead to a greater susceptibility to disease including: early blight, and *Verticillium* Willt.

The amount and timing of nitrogen application are among the most important decisions potato growers have to make. Nitrogen application recommendations are complicated due to differences amongst cultivars, cultivation methods and artificial vine-kill dates. Nitrogen recommendations previously were based on yield goals. Today fertilizer recommendations for the Red River Valley do not include yield goals; instead, they are separated based on irrigated and dryland potato production and further separated based on vine-killing dates and cultivars being grown (Franzen et al., 2021). Early maturing potato cultivars generally require less nitrogen than later maturing cultivars because of an earlier harvest and lower overall expected yield (Zotarelli et al., 2015). Split applications are common recommendations, with some of the nitrogen being applied at planting, and subsequent amounts being applied at emergence and hilling (Rens et al., 2015). Delaying harvest to allow for additional growing days, and subsequent increase in tuber bulking and yield, may lead to an accumulation of disease in the vines and tubers that can be an economic problem for producers. Too late of an application of nitrogen can inhibit vine desiccation, and lead to regrowth of vines before harvest (Boydston et al., 2017).

Nitrogen also can affect the chipping quality of cultivars. Processors of potatoes favor high starch content (a higher specific gravity), and subsequent low sugar content, to assure a lighter chipping color and limit the amount of time and oil required for processors. Nitrogen, especially in shorter growing season environments, can delay tuber initiation resulting in higher sugar content and lower specific gravity making them unsuitable for processing. Excess nitrogen may also lead to storage issues. Tubers grown with excessive nitrogen tend to have a lower specific gravity and higher sugar content, especially reducing sugars, and lower starch content, thus requiring reconditioning in storage before processing.

1.2.1. Nitrogen Leaching and Other Losses

At times growers may over-apply N because the immediate economic cost of the fertilizer and potential yield gains outweigh any potential future economic losses. Any excess in N fertilizer that surpasses the demands of the crop or the ability of the soil type to retain the N may lead to N leaching out of the soil. This is dependent on the plant and cultivar, soil type, climatic conditions, crop management practices, as well as type of fertilizer and application method (Gu & Riley, 2010). The lost nitrogen is volatilized as a gas and released into the atmosphere as ammonia, or it is taken up by the microbes and either released quickly back into the soil after their death, or goes through decomposition and humification into organic matter where it is locked away and inaccessible short term, only to be slowly released overtime (Patil et al., 2010). If moderate or intense rainfall occurs between planting and crop emergence, nitrates or ammonium can also by leached out of the upper layers of the soil horizon by water (Hess et al., 2020).

Nitrogen leaching is caused when nitrogen, which is mobile in water, is leached into the soil out of the zone where the plant roots can access the nutrients and finds their way into the groundwater system causing numerous problems. When all nitrogen is supplied at planting, it is not sufficient for the plants needs for the entire growing season due to leaching or other forms of N loss; this can lead to early senescence (Zhou et al., 2018). Splitting applications of nitrogen between just before or at planting, and just before or after emergence can increase crop nitrogen efficiency and reduce leaching risk (Rens et al., 2018). Errebhi et al. (1998) found that in years of heavy rain and subsequent nitrogen leaching, plots with single nitrogen applications had 83% to 158% higher leaching compared to plots with split N applications. To minimize leaching and synchronize both rate and timing of nitrogen fertilization with the plant needs during the growing season, can be enhanced with the use of efficiency nitrogen fertilizers, such as ESN (Environmentally Smart Nitrogen), a polymer-coated urea product (44-0-0), that slowly controls the release of urea based on soil temperature and moisture levels (Gao et al., 2018).

1.3. Water

The potato plant is dependent on water to transport nutrients that affect its growth and development. Although the potato plant is a heavy feeder and extracts a lot of nutrients and water from the soil, the plant does this rather inefficiently because of its shallow root system (Joshi et al., 2016). Roots grown from an asexually propagated tuber result in finely branched shallow fibrous spreading adventitious roots. True to type cultivars grown from seed have a tap root with many laterals (Welbaum, 2015). Because of this shallow root system, the potato plant is more dependent on regular rainfall, or irrigation, and is more sensitive to drought stress then deeper rooted cereal crops. (Joshi et al., 2016; Zarzyńska et al., 2017). This can create problems in drier climates or when rainfall is variable and is why many potato growing areas utilize irrigation. Water stress treatments may be used in research settings to better understand the efficiency of the potato root system. Zarzyńska et al. (2017) found a direct correlation between the larger root system, and a smaller the decline in yield, when the drought stress treatment was applied.

1.4. Spacing

Planting potato seed pieces at an appropriate distance allows for enough space for root, canopy and tuber development, and nutrient and water acquisition from the soil (Krupek, 2018). Spacing of potato plants influences the desirable tuber size profile for the intended market. Factors that affect spacing include cultivar, environmental conditions, and physiological age of seed tubers. Some cultivars produce more stems per plant and more tubers per plant; thus, to achieve the desired tuber size profile, within-row spacing may need to be increased, compared to a cultivar with fewer stem numbers per plant. Bohl et al. (2011) found that reducing the in-row spacing reduced the tuber number per plant. They also concluded that increasing the within-row spacing of the cultivars Ranger Russet, Russet Norkotah, and Alturas from 20 to 40 cm resulted in not only a difference in the average tuber size but led to an overall reduction in yield.

Type of irrigation does not play a significant role in the effect of within-row spacing on tuber size. One study, conducted under both irrigated and non-irrigated conditions in North America, concluded that a smaller with-in row spacing resulted in reduced average tuber size (Tarkalson, 2011). However, decreasing within-row spacing and subsequently increasing planting density resulted in a greater water requirement.

Physiologically older tuber seedpieces produce more stems and tubers per plant compared to physiological younger tubers (Knowles & Knowles, 2006). A study conducted using the cultivar Ranger Russet and artificially aged seed, reaffirmed that regardless of physiological seed age, decreasing within-row spacing resulted in more tubers per plant (Knowles and Knowles, 2016). In contrast to Bohl et al.(2011), Knowles and Knowles found that this effect was exaggerated in physiologically older seed, compared to younger seed. It was also shown that decreasing within-row spacing resulted in an increase in marketable yield for physiologically younger seed. They concluded that within-row spacing could be adjusted according to relative seed age, and consequently the expected number of stems per plant, to improve both the tuber size distribution and overall crop value.

In addition to the affect that spacing has on potato growth and resulting yield, spacing can also affect the spread of disease and pests. Davis et al. (2015) evaluated the spread of potato virus Y (PVY) and potato leaf roll virus (PLVR) using 30 cm between-row spacing and within-row spacings of 20, 31, 46, 69, and 102 cm. Results indicated that the 20 cm within-row spacing was best for reducing the spread of PVY or PLVR (2015).

Seed spacing also affects other aspects of crop production beyond yield and disease pressure. Canopy closure can lead to increased competition with weeds, reduced water evaporation, and cooler soil temperatures. However, closer within-row seed spacing can also have negative effects, including an increase in potential hot spots for fungal and bacterial infections.

1.5. Production

The potato tuber is metabolically active post-harvest. As a living organism, potato tubers need to be handled carefully to prevent wounds and bruises. Injuries to tubers at harvest can lead to water loss, provide disease entry, and quality reduction. Muddy soil conditions can hinder harvest, but hard dirt clods can cause excessive bruising. Along with harvest and post-harvest mechanical injuries, tubers are also susceptible to pathogens and microbial decay; this may increase the cost of harvest. The current estimated cost per acre to produce non-irrigated Red Norland potatoes in North Dakota and Minnesota is $2,623, while the current estimated cost per acre to produce soybeans is $285 per acre (Swenson, 2017). With such a high investment in potato crops, in-season crop losses for potato farmers can be devastating, and post-harvest losses in storage or during handling can be equally difficult.

1.6. Storage

The tuber of the potato plant is kept in environmentally controlled storage environment for extended periods of times because it is metabolically active. Maintaining high relative humidity and cool temperatures can help maintain similar quality as when the tuber was harvested (Olsen, 2014). Some of the variables that need to be taken into consideration or controlled include temperature, humidity, air circulation, sprout inhibition and disease management. A successful storage begins with a successful harvest. The outer layer of the potato is subject to wounding which is common in harvest and post-harvest handling; decreasing wounding can help maintain physiological dormancy and an increased storage length (Wang et al., 2020). Storage length is cultivar dependent and is commonly assessed by skin set, dry matter content, fry color and sugar content including sucrose, glucose and fructose (Heltoft et al., 2017). Appropriate storage can also manage a potato tuber’s sugar and starch levels and provide a good environment for proper wound healing (Wang et al., 2020).

In storage, potatoes are confronted with several problems including bruising caused by pile weight and distribution (Robinson, 2013). Disease growth and infection can also lead to large losses post-harvest in storage. Bacteria and fungus grow rapidly in wet humid environments or when there is reduced airflow and high amounts of CO_2 (Tournas, 2008). If there is not adequate air circulation in storage throughout the pile, or tubers are harvested wet, or not dried sufficiently post-harvest, such conditions are ideal for disease proliferation may occur in storage. Too dry of an environment can dehydrate tubers and lead to losses.

When the tubers are actively growing the enzymatic pathway that converts sucrose to reducing sugars is blocked. In storage, however, this pathway is unlocked by a vacuolar invertase gene that encodes the protein that breaks down sucrose to glucose and fructose, and the accumulation of these reducing sugars leads to poor frying quality in potatoes (Clasen et al., 2015). High or elevated sucrose levels can be present in tubers at harvest due to early vine kill, heat stress, water stress, or over fertilization. Storage stresses such as low temperatures, or insufficient air flow leads to the conversion of starch to sucrose and a subsequent increase in reducing sugars (Wiberley-Bradford et al., 2014). Work is being done to target and knockout or the genes involved in this pathway to inhibit such stress responses in storage (Clasen et al., 2015).

The golden color associated with potato chips and French fries is a byproduct of the Maillard reaction. The reaction of the reactive carbonyl group of the sugar interacting with the nucleophilic amino group of the amino acid is what gives the color and flavor commonly associated with the fried starch rich products of potatoes (Schouten et al., 2020). Excessive browning due to high reducing sugars causes excessive browning and effects taste. High reducing sugar levels also leads to a sweet taste in the potato tuber’s end product making the tubers unsuitable for potato chips. Some Potato cultivars can be reconditioned in storage. Reconditioning entails storing potatoes at a higher temperature, around 20 to 22 °C for 2 to 5 weeks. This allows the starch to sugars pathway to be reversed and the resynthesis of starch from free sugars. The length of reconditioning depends on the level of reducing sugars in the tuber at the time of harvest or accumulated during storage. Along with reconditioning, storage can also help to heal wounds through suberization (Dwelle, 2003). Too high of a storage temperature hastens the end dormancy, resulting in sprouting may lead to an increase in fungal or bacterial growth. Sprout inhibitors are commonplace in the industry to lengthen storage time, but in recent years their use has been scrutinized and are in decline (Alamar et al., 2017).

1.7. Breeding New Cultivars

Problems encountered when breeding new cultivars would be adapting cultivars to climate, resistance to pests, improved storage and processing qualities, and higher nutrient uptake efficiency. For example, some cultivars have been bred for resistance to late blight (*phytophthora infestans*), Colorado Potato Beetle (*leptinotarsa decemlineata*), Potato virus Y (PVY), *Verticillium* wilt, and nematodes (Sliwka et al, 2011; Cooper et al, 2004; Szajko et al., 2014).

With all the costs and risks involved in growing potatoes, farmers can benefit from new cultivars that result in a better crop return. Breeders look for ways to improve cultivars including increasing the marketable yield. When breeding chip processing or French fry processing potatoes, the focus may be on decreasing sugar content, uniformity in tuber size profile, tuber shape, and increasing specific gravity (Wayumba et al., 2019).

Polyploidy, heterozygosity, and asexual propagation pose obstacles to potato breeders and the potato industry. Advancements are being made in rapid genotyping, marker development, and with tissue culture production (Seibt et al. 2012; Mohapatra & Batra 2017). These techniques may speed up the breeding process. It has long been assumed that tetraploid potato is essential for high yield. However, there is a global industry push challenging this viewpoint. Creation of diploid potato cultivars that can be reproduced for true seed is a goal of many public and private breeding programs; these efforts are still in their early stages (Jansky et. al., 2016).

1.8. Failure to Adopt New Agronomics

Producing new potato clones takes many recourses and can be a long and very time-consuming process (Haynes et al., 2012). However, the amount of time and money invested does not guarantee a cultivar has a high adoption rate by producers or processors. Successful adoption of a new potato cultivar by growers requires correct and accurate information about their responses to agronomic factors, including nitrogen requirements (Sun et al., 2017). One example of low adoption from the NDSU breeding program is the cultivar Dakota Diamond, a high-yielding cold chipping cultivar with a low nitrogen requirement and preferential avoidance by the Colorado potato beetle (Thompson et al. 2008). When some producers used their normal nitrogen application rates for common cultivars they were growing, signs of excessive nitrogen application were observed, such as large vine production, delayed tuberization and maturity, reduced yield, high sucrose levels and poor chip quality. The potatoes could not be chipped straight out of the field but required conditioning in storage first. Instead of adjusting their agronomic practices the Dakota Diamond was assumed to be difficult to manage compared to the current cultivars, and today the total acreage of Dakota Diamond grown in North Dakota, is minimal to non-existent (A. Thompson, personal communication, August 4, 2020).

Often, the adoption rate of a new potato cultivar does not happen very quickly and is quite low. The 10 potato cultivars released by the NDSU potato breeding program in the 20 year period from 1980-2000 account for 10% total acreage and 12% total acreage of the certified seed acreage in North Dakota (North Dakota State Seed Department, 2018) and Minnesota (PAA USA Seed Acres, 2018), respectively. The 10 cultivars released in the 20 years since that time (2000-2020) only make up 2% and 6% of total certified seed acreage in North Dakota and Minnesota.

The genetic complexity of potatoes means breeding takes time. Bad marketing and unfamiliarity with a cultivar's name and growth habits, as well as its culinary attributes and market success make it difficult to convince growers to switch over to newer cultivars. Growers are comfortable with particular cultivars because they know how they perform in good and bad years. Manufacturers have their processes tailored to a specific size profile and specific gravity amongst other attributes. Markets and consumers are used to flavor, texture, and appearance of particular cultivars; they know how a "potato" is supposed to taste and look and are hesitant to branch out. As newer cultivars are being released better information needs to be released along cultivar specific management, as well as a list of positive benefits that make adoption of the new cultivar beneficial for the growers and current markets. It is ultimately up to time, and the work of extension and education to get greater and faster adoption rates for new potato cultivars upon release. (A. Thompson, personal communication, March 6, 2019; Dwelle & Love, 2003).

The objectives of this study were to conduct an experiment to determine the optimal agronomic practices including nitrogen fertilization rate, and within-row spacing of plants, for ND7799c-1 and ND7519-1, both advancing chip processing selections in the North Dakota State University Potato Breeding Program. The goal of this project then is to utilize the data collected and through extension and education ensure a greater adoption rate for the advanced selections upon release, and provide market success for both producers and processors in the Red River Valley.

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2. NITROGEN AND SPACING REQUIREMENTS FOR CHIPPING SELECTIONS ND7799C-1 AND ND7519-1

2.1. Abstract

A study was carried out to determine the best nitrogen fertilization rate and within-row spacing, for North Dakota State University's advanced chipping selections ND7799c-1 and ND7519-1, to ensure successful adoption by local potato producers. Measurements included nitrogen uptake, Hunter L value, glucose and sucrose content, and specific gravity. ND7799c-1 grown at 23 cm spacing had a similar marketable yield to the current industry standard, Dakota Pearl. ND7519-1 yielded similarly to Dakota Pearl, across all spacings. Nitrogen rate was not a significant factor for yield across all rates, within-row spacings or genotype. Both advanced selections had lower sucrose and glucose levels at the time of harvest compared to Dakota Pearl. ND7799c-1 could be stored for 8 months, and ND7519-1 could be stored for 6 to 8 months before a decrease in chip quality occurred. The research indicates these advanced selections can benefit producers in the Northern Plains production area.

2.2. Introduction

There is a continuous need to develop new potato cultivars because of climate change, shifting market demands, and rapid adaptability of insects, pathogens, and diseases. Potato breeders have worked to develop cultivars with increased nutrient and water use efficiency, disease resistance, and improved capacity for long-term storage (Armstrong et al., 2019; Fulladolsa et al., 2015). Improving nitrogen uptake efficiency (NUE) addresses concerns about high production costs and environmental damage that can come from using excessive nitrogen (Tiwari et al., 2018). In addition to these traits, chipping potatoes are bred with specific traits including high dry matter content and low sugar accumulation, which affect chip color and processing quality (Wayumba et al., 2019).

It can take a decade or more of research and thousands of dollars to develop a new potato cultivar. In a recent cost analysis of potato breeding field trials, the cost ranged from $25,000 to $41,000 for one hectacre of potatoes (Slater et al., 2013). Compounded over years and trials, it can be very expensive to successfully develop a new potato cultivar. No amount of time or money can guarantee a new cultivar's success if potato producers are not successful in growing or storing tubers, or if tubers do not meet processing requirements.

Even after a breeding selection is named, it still can take time to reach commercial production because of the time and cost of asexual seed propagation. Correct and accurate information about responses of new potato cultivars to agronomic practices is important to producers and can result in higher adoption rates. Nitrogen is an important factor for plant growth and development (Jones et al., 2020; Stefaniak et al., 2021; Sun et al., 2017; Tiwari et al., 2018). Additionally, environmental factors, grower and manufacturer preferences, combined with ever-changing market pressures, influence the adoption rates of new cultivars (Devaux et al., 2020). Even when new cultivars are released with specific traits to benefit the potato industry, some habitual agricultural practices may not be optimum for the production of a new cultivar and it can be mistakenly labeled as a failure. One such example was Dakota Diamond, a cultivar released from the NDSU breeding program. This cultivar had a higher yield potential than other common chipping potatoes at the time it was released, in addition to having higher marketable yield in both irrigated and non-irrigated field trails (Thompson et al., 2008). However, this cultivar required less nitrogen fertilizer than the standard chipping potato cultivars. Standard nitrogen fertilization rates were too high, resulting in excessive vegetative growth, decreased specific gravity, reduced yield, and an increase in sugar content that had negative effects on processing quality, storage, and grower acceptance (A. Thompson, personal communication, March 6, 2019).

Two advancing selections from the NDSU potato breeding program, ND7799c-1 and ND7519-1, have demonstrated promising traits. These selections have “cold chipping” potential, thus they may be able to chip directly from cold storage without the need for reconditioning. They also usually can be chipped immediately after harvest without the need to recondition the tubers in storage. ND7799c-1 resulted from a cross between genetic lines Dakota Pearl and NY115. It has a high yield potential with a uniform tuber size profile, along with a high specific gravity (1.086+) across irrigated and non-irrigated field sites, and can chip well from 5.5 °C storage. ND7519-1 resulted from a cross between ND3828-15 and W1353. It has excellent chipping qualities, medium-high yield, with a high specific gravity (1.090+) across irrigated and non-irrigated locations, and can also chip well from 5.5 °C storage. Little is known about the agronomic management of ND7799c-1 and ND7519-1 because limited work has been completed. The objective this study was to determine optimal nitrogen rate and within-row spacing for ND7799c-1 and ND7519-1 for both tuber yield and chipping quality for non-irrigated plots. It was hypothesized that these potential new cultivars would have similar yield and quality when compared to an industry standard Dakota Pearl.

2.3. Materials and Methods

Field trials were conducted in 2018 and 2019 near Hoople, North Dakota (N 48° 32.0828’, W 97° 38.0885’). In 2018, the soil was a clay loam with 2.0% organic matter. The previous year the land was left fallow. In 2019, the soil was a clay loam with 2.5% organic matter content, a pH of 8.4, and 31.4 lb of N ha^{-1} of soil residual nitrogen. The soil in the research plots for each year is classified as a moderately well drained Glydon silt loam, with a 0 to 2 percent slope.

2.3.1. Experimental Design

Trials were established in 2018 and 2019 near Hoople, ND in a non-irrigated potato field. In 2018, the advanced selections ND7799c-1 and an industry standard Dakota Pearl were grown. In 2019, ND7799c-1, ND7519-1, and an industry standard Dakota Pearl were grown. The experiment utilized a randomized complete block design with factorial arrangement of treatments. Treatments included genotype, nitrogen fertilizer rate (90, 134, 179, and 224 kg of N ha^{-1}), and within-row spacing of seed pieces (15, 23, and 31 cm). Trials were machine planted with a two-row planter on 8 and 13 June 2018 (a rainstorm caused a delay in planting), and 3 June 2019. Each treatment was replicated four times. Spacing treatments were based off a range of common spacings used in chipping potato production. Nitrogen treatments were determined as the best possible increments in a range of possible N rates from low to high. The nitrogen fertilizer was broadcast prior to planting each year, at rates of 90, 134, 179, and 224 kg of N ha^{-1}. The source of nitrogen for all treatment rates was urea (46% N). Plots were 6.3 meters wide and 7.62 meters long. Plots were two rows wide labeled A and B; Row A was for measuring heights and harvesting of the tubers, Row B was used in assessing nitrogen levels. Border rows were utilized to minimize edge effect.

2.3.2. Crop Management

Research plots were grown in a non-irrigation area of potato production, relying on precipitation for water. All other production practices were followed according to the North Dakota State University and University of Minnesota recommended potato production practices (Bissonnette et al, 1993).

2.3.3. In-Season Monitoring for N Uptake Efficiency

In 2019, nitrogen uptake efficiency (NUE) was determined at 5, 7, 9 and 11 weeks after emergence. The above ground plant tissue from three plants was removed from row B and fresh weight was determined. A subsample of 0.9 kg was retained and dried at 40 °C in paper bags for 2 weeks. Dried tissue was processed by Agvise Laboratories (Northwood, ND) and for percent total N determination using the Dumas combustion method in an Elementar rapid N analyzer (Jones & Case, 1990). NUE was calculated by taking the percent N content of the dry plants multiplied by the weight of the plants and dividing it by the total nitrogen applied in kg ha^{-1} for the plot.

$$Nitrogen\ Uptake\ Efficiency\ (NUE) = \frac{Percent\ N\ of\ plant\ x\ Weight\ of\ the\ plant(g)}{Total\ nitrogen\ applied\ (kg\ ha^{-1})}$$

2.3.4. Tuber Yield

Potato plant vines were flailed tubers were then harvested on 4 September 2018, and 9 September 2019, approximately two weeks after vine-kill. Tubers were stored at 13 °C for four weeks for wound healing. After four weeks tubers were graded on a Kerian Speed Sizer calibrated to sort potato tubers as oversized (greater than 8.9 cm diameter), marketable chipsize (4.8-8.9 cm diameter), and undersized (less than 4.8 cm diameter). Grading was done according to the USA Snacking Nutrition and Convenience (SNAC) International Chip Trial grading standards for potatoes for chipping (Gould & Plimpton, 1985). Total tuber numbers in each size category were also counted.

2.3.5. Tuber Quality and Post-Harvest Monitoring

For each cultivar and nitrogen treatment at the 23 cm within-row spacing, 10 marketable chipsize tubers from each of these plots were arbitrarily selected after grading to test the storage capacity of each treatment. After suberization, a subsample of 10 tubers were selected for immediate evaluation of specific gravity, sucrose and glucose level, and Hunter L-value for processed potato chips. The remaining tubers were arbitrarily divided into two groups and stored at 7.2 and 9.9 °C for 8 months. At 3, 6, and 8 months after grading and being placed into storage, subsamples of 10 tubers from each storage temperature were evaluated for specific gravity, sucrose and glucose level, and Hunter scores determined for chips.

Specific gravity was determined by taking the tubers weight in air and then weight in water. The specific gravity value was calculated by taking total tuber weight in air divided by the weight in air minus the weight in the water (Lulai & Orr, 1979).

To measure sucrose and glucose levels, 200g of the potato tuber tissue was pressed through a Waring juicer with 150 ml of a sodium phosphate buffer. Distilled water was then added to the sample until a volume of 275 ml was achieved. The sample was placed into the refrigerator for 30 minutes to allow for settling. The sample was then put into a YSI analytical machine with a sucrose and glucose membrane. Sucrose content and Glucose content were then calculated from mg ml^{-1} to mg g^{-1} and compared to the target maximum sucrose and glucose content established by Stark et al. (2020).

The Hunter L value was used to assess chip color after frying. Thirty chips were fried for 2 minutes at 365 °F and Hunter score was used to assess chip quality color after frying following the methods of Hunter and Harold (1987). This Hunter score was obtained using a D25-NC colorimeter.

2.4. Data Analysis

Data collected met the assumptions of normally and equally distributed data according to the Shapiro-Wilk test (Shapiro & Wilk, 1965). Analyses were computed for yield, nitrogen content, and chip quality attributes. Because of the addition of ND7519-1 to the study after 2018, and significant differences in environmental conditions between years, separate statistical models were run for each year. All statistical analyses were computed using the statistical analysis software R version 3.6.1.

ND7799c-1 was compared to the industry check Dakota Pearl in 2018. Using a linear model the ANOVAs were analyzed using replicate, genotype, nitrogen rate, and within-row spacing as fixed effects. Statistical analysis was performed for total and marketable yield. Four separate chip quality and post-harvest linear models were run for sucrose content, glucose content, specific gravity, and Hunter score. Each post-harvest model was considered for statistical differences between cultivars at varying nitrogen rates and storage temperatures as a function of time.

ND7799c-1 and ND7519-1 were compared to Dakota Pearl in 2019. The results were analyzed using a linear model taking into account the effects of genotype, nitrogen rate and within-row spacing. Data analysis were run for total, marketable, undersized and oversized yields. Four separate chip quality and post-harvest linear models were run for sucrose content, glucose content, specific gravity, and Hunter L Value. Each post-harvest model was considered for statistical differences between genotypes at varying nitrogen rates and different storage temperatures as a function of duration in months of storage. The N uptake efficiencies (Weih et al., 2011) were evaluated by genotype and nitrogen rate and as a function of weeks after planting. ANOVA and a Tukey separation of means were run at $\alpha=0.05$ for all statistical models.

2.5. Results and Discussion

2.5.1. Weather

Overall rainfall was considered numerically less than the average for the Crystal NDAWN weather station, in 2018 and 2019. There was 45 mm more precipitation throughout the growing season in 2018 compared to 2019. Moreover, during the earlier part of the growing season during tuber initiation and the start of tuber bulking 2018 had 66 mm more rainfall. A late rainstorm in 2019 came just before harvest that brought up the overall totals but did little for the crop. Overall, 2019 had less growing degree days than 2018 by 81 (Table 1).

Table 1. Total and monthly average growing degree days (GDD) and rainfall in 2018-2019 at Hoople ND, as well as monthly averages collected from the NDAWN weather station at Crystal, ND for Comparison.

	Growing degree days accumulated		Rainfall (mm)		Crystal Weather Station Monthly Normals Since 2018[1]	
	Year		Year		GDD	Rainfall (mm)
Month	2018	2019	2018	2019		
June	399 [2]	361	106	68	306	95
July	418	369	51	23	402	76
August	244	250	19	40	378	67
Total	1061[3]	980	176	131	1086	238

[1] Crystal NDAWN weather station is located approximately 13km away from each field site.

[2] Growing degree days were calculated using the formula $GDD = [(minT + maxT)/2 - 7\ °C]$ *(Sands et al., 1979).*

[3] Total growing degree days and rainfall were calculated using the day of planting as the start date and the day the vines were killed as the last day.

A potato plant can experience stress when less water is available especially during tuber set and tuber bulking phases. Water stress, especially during the tuber bulking phase, has been shown to have a negative effect on yield, a reduction in the formation of new leaves, and an increase in water loss through evapotranspiration (Aliche et al., 2018). Total and marketable yield for both Dakota Pearl and ND7799c-1 were numerically smaller in 2019 than 2018. This reduced numerical yield for all genetic lines in 2019 may be evidence of water stress. The data suggests the effect of water stress varied by genotype. Water stress appeared to have a much larger effect numerically across the two years on ND7799c-1 compared to Dakota Pearl. This implies that ND7799c-1 may be less efficient at acquiring or using water. Further research is warranted to confirm this.

ND7799c-1 also produced numerically three times the amount of oversized tubers in 2019 compared to 2018. This is similar to findings of a study at the Heber University of Jerusalem where some genetic lines were subjected to intentional water stress produced more oversized tubers (Levy, 1983). Water stress can cause chip quality problems because of higher reducing sugar accumulation during the growing season. This may result in a darker chip color. Glucose levels were numerically higher at harvest in 2019 than 2018 as well as a numerically higher Hunter L value (darker fry color). Specific gravities were also numerically lower for all lines at harvest. These findings support a study done in 2008 that showed greater water stress was associated with progressively darker chip frying color (Eldredge et al., 2008). The results for 2019 can be examined considering potential water stress, which can be common in dry land conditions. In irrigated fields, water deficiencies in tuber yield and quality during the growing season can be negated by proper water management (Levy et al., 2013).

2.5.2. Nitrogen and Nitrogen Uptake Efficiency

The effect of N on NUE was significant across all genotypes (Table 2). ND7519-1 had the consistently highest NUE throughout the growing season. Initially Dakota Pearl and ND7519-1 showed no difference when comparing NUE but at 50 DAP the NUE of Dakota Pearl was statistically lower and remained throughout assessment. ND7799c-1 initially had a lower NUE, but at 65 DAP showed no difference compared to ND7519-1.

N rate was a significant factor when determining NUE (Table 3). The lowest amount of nitrogen applied, 90 kg ha^{-1}, correlated with the highest NUE overall, without affecting yield. Using the lower amount of nitrogen can save on fertilizer costs, application costs and environmental concerns of excessive nitrogen in the soil, without compromising yield. It appears in 2019 that any amount of N applied greater than 90 kg N ha^{-1} does little for these genotypes efficiency, leaving the excess N unused by the potato plants either lost by denitrification, volatilization, or being leached into the soil biome beyond the potatoes root zones. This could be because the field was not irrigated in this study and relied on precipitation. Further research needs to be conducted to determine optimal N rates for ND7799c-1 and ND7519-1 in irrigated potato production. Additional water would provide for more N mobility in plant uptake and leaching and has the potential to exaggerate some of the differences seen or unseen to statistically significant levels. This has been indicated in the research of Belanger et al. (2002) where it was shown that with irrigation an increase in N directly correlates with an increase in yield.

Table 2. 2019 NUE levels for Dakota Pearl, ND7519-1, and ND7799c-1, at Hoople, ND.

Cultivar	Nitrogen Uptake Efficiency (%) DAP			
	35 DAP	50 DAP	65 DAP	77 DAP
Dakota Pearl	5.3 *a*[1]	3.0 *b*	3.6 *a*	2.3 *b*
ND7519-1	5.5 *a*	3.7 *a*	4.0 *a*	2.7 *a*
ND7799c-1	3.6 *b*	3.3 *b*	3.7 *a*	2.5 *ab*

[1] Data points in the same column were analyzed together using the same model and when followed by the same letter in a column are not significantly different according to Tukey pair-wise comparison at P = 0.05

Table 3. Combined NUE for Dakota Pearl, ND7519-1, and ND7799c-1 analyzed by nitrogen rate during the 2019 growing season at Hoople, ND.

Nitrogen Rate (kg ha^{-1})	Nitrogen Uptake Efficiency (%) DAP			
	35 DAP	50 DAP	65 DAP	77 DAP
90	7.6 *a*[1]	5.1 *a*	6.0 *a*	3.8 *a*
134	4.9 *b*	3.6 *b*	3.7 b	2.6 *b*
179	3.5 *b*	2.5 c	3.1 *bc*	2.0 *c*
224	3.3 *b*	2.2 *c*	2.3 *c*	1.6 *d*

[1] Data points in the same column were analyzed using the same model, and when followed by the same letter within a column are not significantly different according to Tukey pair-wise comparison at P = 0.05

Increasing the N rate from 90 to 224 kg ha^{-1} had no effect on marketable or total yield in 2018. In 2019 the N was a statistically significant factor for marketable yield, but no correlation was found with an increase in N rate compared to an increase in marketable yield (Table 4). Sucrose levels was the only post-harvest quality check effected by N in 2018 with higher additional N applied resulting in higher sucrose levels. In 2019 N rate did not influence chipping quality factors such as sucrose, glucose, Hunter score, or specific gravity. This was confirmation of previous research done by Long et al. (2004) that shows that genotype is the major contributor to post harvest tuber characteristics and mostly independent from in-season treatments like N. Unlike the study however which found some significance to specific gravity and the amount of N applied, no such correlation was found for all genetic lines tested in this study. Although specific gravity is a measure of water and dry matter accumulation, the results of this study suggest that for some genetic lines water, not N level, is the greater limiting factor.

Table 4. Marketable yield analyzed by nitrogen rate in 2019.

Nitrogen rate (kg ha^{-1})	Marketable yield (MT ha^{-1})
90	24 *a*[1]
134	21 *ab*
179	20 *b*
224	21 *ab*

[1] Numbers followed by the same letter in a column are not significantly different according to Tukey pair-wise comparison at P = 0.05

In 2018 nitrogen rates applied during the growing season did affect sucrose values at the time of harvest (Table 5), but the data showed no such correlation in 2019. This indicates that greater precipitation levels could enhance the effect of nitrogen on post-harvest chipping and storage qualities due to greater mobility and uptake by the potato plants. The lowest rate of nitrogen had the lowest impact on sucrose levels. Considering nitrogen had no effect on overall yield, for both years, the lower the rate of nitrogen applied would be the most beneficial when considering not only cost but post-harvest chipping and storage qualities without sacrificing profit or yield potential.

Table 5. Sucrose content across all genotypes analyzed by nitrogen rate in 2018[1].

Nitrogen rate (kg ha^{-1})	Sucrose at harvest mg g^{-1}
90	0.80 *b*
134	0.95 *ab*
179	0.96 *ab*
224	1.08 *a*

[1] Numbers followed by the same letter in a column are not significantly different according to Tukey pair-wise comparison at P = 0.05

2.5.3. Yield

Table 6. Total, undersized (diameter smaller than 4.8 cm), oversized (diameter bigger than 8.9 cm), and marketable yield (US No.1) in MT ha^{-1} for Dakota Pearl, ND7519-1 and ND7799c-1 at within-row spacings of 15, 23 and 31 cm grown at Hoople, ND in 2018 and 2019.

	2018				2019			
Genetic Line	US No. 1	Total	<4.8 cm	>8.9 cm	US No. 1	Total	<4.8 cm	>8.9cm
Dakota Pearl								
15cm	28 *ab* [1]	31 *ab*	2 *a*	2 *bc*	25 *a*	29 *ab*	1 *b*	2 *b*
23cm	25 *bc*	27 *c*	1 *b*	1 *c*	25 *a*	28 *a*	1 *b*	2 *b*
31cm	25 *bc*	27 *bc*	1 *b*	0 *c*	23 *a*	26 *b*	0 *b*	2 *b*
ND7799c-1								
15cm	24 *bc*	26 *c*	2 *ab*	1 *c*	20 *b*	26 *ab*	0 *c*	6 *a*
23cm	30 *a*	34 *a*	1 *c*	3 *a*	18 *b*	27 *a*	0 *c*	9 *a*
31cm	21 *c*	24 *c*	0 *c*	3 *ab*	15 *b*	20 *b*	0 *c*	5 *a*
ND7519-1								
15cm	-	-	-	-	20 *a*	23 *ab*	2 *a*	0 *b*
23cm	-	-	-	-	24 *a*	26 *a*	2 *a*	0 *b*
31cm	-	-	-	-	23 *a*	24 *b*	1 *a*	0 *b*

[1] Numbers in the same column were analyzed using the same model, and when followed by the same letter within a column are not significantly different according to Tukey pair-wise comparison at P = 0.05

In 2018, within-row spacing and genotype were statistically significant factors for total, marketable, undersized, and oversized yield (Table 6). ND7799c-1 had the highest total and marketable yield at 23cm spacing and was statistically similar to Dakota Pearl planted at 15 cm within-row spacing. In 2019 ND7799c-1 had statistically similar total yield across all spacings compared to Dakota Pearl. ND7799c-1 had, however, a statistically lower marketable yield compared to the other genetic lines, across all spacings in 2019. ND7799c-1 had only 75% marketable yield in 2019, compared to 89% in 2018. Dakota Pearl had 86% of total yield being marketable in 2019 and 92% marketable in 2018. This data indicates that ND7799c-1 had a numerically greater reduction in marketable yield between the two years, compared to Dakota Pearl, potentially due to water stress. As aforementioned, ND7799c-1 produced more oversized tubers in 2019 by numerically three times as much, compared to 2018; this was numerically greater than Dakota Pearl. ND7799c-1 also produced the least number of undersized tubers in 2019 compared to the other genotypes. The data indicates a reduction in undersized tuber yield between 2018 and 2019, which is contrary to a previous study by King et al. (2004) in Idaho that demonstrated for Russet Burbank potatoes in water stressed conditions produced fewer marketable sized tubers with a greater number of undersized tubers. The researchers concluded that due to water stress overall tuber growth rate is reduced, resulting in smaller tubers (King et al., 2004). Mackerron and Jefferies (add year here) reported that the effect of water stress on yield and size profile varied across genetic lines as well as the timing of induced water stress. When potato plants experienced water stress the number of tubers in the smaller size categories increased. In addition, they found that when water stress was induced before 50% emergence, the total number of tubers per plant were reduced. When the water stress was introduced sat the onset of tuber initiation no reduction was observed. The researchers concluded that the overall size of tubers decreased but the number of tubers per plant were reduced when water stress was introduced before tuber initiation (Mackerron & Jefferies 1986). ND7799c-1 however, did not produce more undersized tubers, instead it showed results similar to a study performed by Aliche et al. (2018) that showed that when water stress was introduced some genetic lines produced more oversized tubers

A possible explanation of why ND7799c-1 produces higher number of oversized tubers could be that this genotype initiates tubers later the Dakota Pearl and ND7519-1, thus allowing for more photosynthates going to fewer tubers; this would result in larger tubers. Another explanation can be drawn from a study by Walworth and Carling (2002) where they found that regardless of when tubers were set, the number of tubers per plant was fluid and tubers could be reabsorbed during the season. They found this fluidity cultivar dependent, and that for several genetic lines tested, overall tuber numbers declined at some point during the season. (Walworth and Carling, 2002). ND7799c-1 could reabsorb tubers already set and reallocating those nutrients, and dry matter into larger tubers. Additional research is warranted to study the physiological effects of water stress on tuber size profile for the genetic line ND7799c-1.

ND7799c-1 yielded the lowest marketable yield at 31cm within-row spacing in both year models. These findings are similar to a study done in Prince Edward Island where a decrease in yield of the cultivar AC Novachip was found when in-row spacing was increased from 25.4 to 30.5 cm (Arsenault & Malone, 1999). The effect of within-row spacing on marketable yield varied between years for ND7799c-1. In 2019, under potential water stressed conditions, ND7799c-1 had a numerically higher marketable yield at 15 cm within-row spacing compared to 23 cm which produced the highest marketable yield in 2018 (Table 6). This implies that ND7799c-1 may produce more marketable size tubers at closer within-row spacings in water stressed conditions.

In 2019 ND7519-1 had a statically lower total yield than Dakota Pearl but saw no significant difference in marketable yield compared to Dakota Pearl across all within-row spacings (Table 6). This is contrary to a study in Michigan that found that for several chipping cultivars, narrow seed piece spacing consistently produced the highest U.S. No. 1 yield (Long et al., 2004). This may be an indication that ND7519-1 is more efficient in nutrient acquisition and water retention. Even though ND7519-1 produced the most undersized tubers in 2019, it still had the highest ratio of marketable yield for all genetic lines tested to total yield at 87%.

2.5.4. Specific Gravity, Storage, and Chipping Quality

In 2018 and 2019 ND7799c-1 had a lower specific gravity at harvest compared to Dakota Pearl (Table 7). In 2018 however, ND7799c-1 had a similar specific gravity level compared to Dakota Pearl throughout 8 months of storage at both 7.2 and 9.9 ℃. In 2019 specific gravity remained lower than Dakota Pearl throughout 8 months of storage at both 7.2 and 9.9 ℃. Although the specific gravity recorded for both years is lower than compared to the industry standard, this still indicates that ND7799c-1 would have a moderate chipping quality throughout storage for both years (Kleinkopf et al., 1987; Hassel et al., 1997). ND7519-1 had a lower specific gravity at the time of harvest but saw no difference statistically throughout 6 months of storage, and having a higher specific gravity than both Dakota Pearl and ND7799c-1 after 8 months of storage. Specific gravities for ND7519-1 showed good chipping potential across all temperatures and storage lengths.

Table 7. Specific gravity of Dakota Pearl, ND7519-1, and ND7799c-1 at harvest, 3, 6, and 8 months of storage at 7.2°C and 9.9°C for 2018 and 2019.

	Specific Gravity[1]							
	2018				2019			
	Timing (months)				Timing (months)			
Cultivar	0	3	6	8	0	3	6	8
7.2 °C[1]								
Dakota Pearl	1.078 *a*[2]	1.080 [3]	1.081	1.080	1.075 *a*	1.073 *a*	1.073 *a*	1.076 *b*
ND7799c-1	1.074 *b*	1.079	1.080	1.080	1.065 *c*	1.063 *b*	1.059 *b*	1.067 *c*
ND7519-1	-	-	-	-	1.070 *b*	1.068 *b*	1.075 *a*	1.080 *a*
9.9 °C								
Dakota Pearl	1.078 *a*	1.082	1.078	1.081	1.075 *a*	1.073 *a*	1.066 *a*	1.070 *b*
ND7799c-1	1.074 *b*	1.080	1.081	1.080	1.065 *c*	1.062 *b*	1.058 *b*	1.064 *c*
ND7519-1	-	-	-	-	1.070 *b*	1.072 *a*	1.067 *a*	1.072 *a*

[1] Data points were not compared statistically across different temperatures

[2] Data points in the same column and temperature range were analyzed using the same model, and when followed by the same letter within a column are not significantly different according to Tukey pair-wise comparison at P = 0.05

[3] Data points no followed by any letter, showed no statistical significance.

In both 2018 and 2019 Sucrose levels at the time of harvest and throughout storage at both 7.2 and 9.9 °C were statistically lower for ND7799c-1 compared to Dakota Pearl and were all well below industry maximum values (Table 4). Nitrogen was significant when looking at sucrose levels, and higher rates of nitrogen applied resulted in higher levels of sucrose at harvest (Table 5). After 3 months of storage nitrogen no longer showed a significant effect on sucrose level.

Table 8. Sucrose content of Dakota Pearl, ND7519-1, and ND7799c-1 at harvest, 3, 6, and 8 months of storage at 7.2°C and 9.9°C in 2018 and 2019.

	Sucrose levels^2 (mg g^{-1})							
	2018				2019			
	Storage time (months)				Storage time (months)			
Cultivar	0	3	6	8	0	3	6	8
7.2 °C [2]								
Dakota Pearl	1.08 *b*[1,3]	0.54 *b*	0.58 *b*	0.99 *b*	1.03 *c*	0.76 [4]	1.30	1.92
ND7799c-1	0.82 *a*	0.38 *a*	0.39 *a*	0.73 *a*	0.51 *a*	0.57	1.28	2.39
ND7519-1	-	-	-	-	0.61 *b*	0.64	1.03	2.14
9.9 °C								
Dakota Pearl	1.08 *B*	0.37 *B*	0.48 *B*	0.92 *B*	1.03 *C*	0.52	1.79	1.51
ND7799c-1	0.82 *A*	0.24 *A*	0.29 *A*	0.75 *A*	0.51 *A*	0.39	1.18	1.46
ND7519-1	-	-	-	-	0.61 *B*	0.38	1.17	2.04

[1] Target maximum for sucrose content at harvest is 1.5 mg g^{-1} FW (Stark et al., 2020). Target maximum for post-harvest is 1.0 mg g^{-1} FW (Stark et al., 2020).

[2] Data points were not compared statistically across different temperatures

[3] Data points in the same column and temperature range were analyzed using the same model, and when followed by the same letter within a column are not significantly different according to Tukey pair-wise comparison at P = 0.05

[4] Data points no followed by any letter, showed no statistical significance.

ND7799c-1 and Dakota Pearl remained below the maximum requirement for sucrose in 2018 and could be stored 8 months. However, this would need to be monitored on a year-by-year basis because in 2019 when exposed to potentially more water stress, ND7799c-1 had exceeded the maximum post-harvest sucrose level requirement and would not be suitable to chip after 8 months of storage across in either storage temperature. This time period was longer than Dakota Pearl which stored for only 6 months at 9.9 °C before exceeding maximum allowable sucrose values in 2019, thus lending an advantage of ND7799C-1 even under water stressed conditions.

ND7519-1 had lower sucrose levels compared to Dakota Pearl at harvest up until 8 months of storage at both 7.2 and 9.9. After 8 months of storage, ND7519-1 had higher levels of sucrose at both storage temperatures and had exceeded the target maximum for sucrose content. When ND7519-1 was stored at a lower temperature, sucrose levels were higher, indicating

ND7519-1 chipped better following storage at the higher temperature of 9.9 °C. This is similar to other studies which have indicated that sugar accumulation, including sucrose, is higher for colder storage temperatures (Coffin et al., 1987; Matsuura-Endo et al., 2004; Wiberley-Bradford et al., 2014). This can be attributed to stress at lower temperatures which can activate pathways converting starch to sugar.

Glucose levels were statistically lower at the time of harvest for ND7799c-1 compared to Dakota Pearl in both 2018 and 2019 (Table 9). At harvest, glucose levels were numerically higher in 2019 than they were in 2018. This is contrary to the findings of André et al. (2009) where water stress caused a significant decrease in glucose levels across three cultivars: Guincho Negra, Sullu and Sipancachi. This data could indicate that water stress did not have as high of an impact on glucose levels of these genetic lines. During storage in 2019, glucose levels rapidly achieved similar values to those in 2018 after 3 months. ND7519-1 had no significant difference in glucose levels up until 8 months of storage when compared to Dakota Pearl (Table 9). At 8 months of storage ND7519-1 had a significantly higher glucose levels at both storage temperatures. At 9.9 °C at 8 months ND7519-1 had exceeded the target maximum while Dakota Pearl remained below. Glucose levels were higher when stored at 7.2 °C for shorter-term but when stored for longer than 6 months, storing the tubers at a higher temperature showed a higher glucose content. This indicates that when storing ND7519-1 for long periods of time would be better stored at the higher temperature.

Table 9. Glucose content of Dakota Pearl, ND7519-1, and ND7799c-1 at harvest, 3, 6, and 8 months of storage at 7.2°C and 9.9°C for 2018 and 2019.

	Glucose levels[2] (mg g^{-1})							
	2018				2019			
	Timing (months)				Timing (months)			
Cultivar	0	3	6	8	0	3	6	8
7.2 °C[1]								
Dakota Pearl	0.08 [2,3]	0.06	0.01 *a*	0.01 *a*	0.29 *b*[4]	0.07	0.01 *a*	0.01 *a*
ND7799c-1	0.07	0.05	0.03 *b*	0.02 *b*	0.12 *a*	0.07	0.05 *b*	0.10 *b*
ND7519-1	-	-	-	-	0.35 *b*	0.10	0.00 *b*	0.19 *c*
9.9 °C								
Dakota Pearl	0.08	0.03	0.01	0.01	0.29 *B*	0.03	0.01 *B*	0.02 *A*
ND7799c-1	0.07	0.04	0.01	0.01	0.12 *A*	0.05	0.04 *A*	0.11 *B*
ND7519-1	-	-	-	-	0.35 *B*	0.01	0.01 *B*	0.58 *C*

[1] Data points were not compared statistically across different temperatures

[2] Target maximum for glucose levels at harvest and post-harvest is .35 mg g^{-1} FW (Stark et al., 2020).

[3] Data points in the same column and temperature range were analyzed using the same model, and when followed by the same letter within a column are not significantly different according to Tukey pair-wise comparison at P = 0.05

[4] Data points no followed by any letter, showed no statistical significance.

Hunter L values were statistically higher for ND7799c-1 at harvest, indicating lighter chipping color straight out of the field (Table 10). When stored at 9.9 °C there was no difference in Hunter scores between the two cultivars. At 7.2 °C there was no statistical difference for 3 and 6 months of storage, but at 8 months of storage ND7799c-1 had a lower Hunter score than Dakota Pearl. ND7519-1 had no statistical difference in Hunter L value at harvest and up until 8 months of storage compared to Dakota Pearl. (Table 10). At 8 months of storage ND7519-1 had a lower Hunter score than Dakota Pearl at both storage temperatures but were still within acceptable ranges for chipping potatoes. Data indicate that the optimal storage temperature, for all genetic lines up until 8 months of storage, for a higher hunter L value is 9.9 °C. ND7519-1 broke the trend, and after 8 months of storage had a lighter chip color when stored at 7.2 °C compared to 9.9 °C. This general trend however was inconsistent with findings from Herrman et al. (1996) where they found that tubers stored at 10 °C produced darker potato chips than tubers receiving a cold-storage treatment where the majority storage time was below 10 °C.

Table 10. Hunter-L value of Dakota Pearl, ND7519-1, and ND7799c-1 at harvest, 3, 6, and 8 months of storage stored at 7.2°C and 9.9°C for 2018 and 2019.

	Hunter L Value (1-100) [1]							
	2018				2019			
	Timing (months)				Timing (months)			
Cultivar	0	3	6	8	0	3	6	8
7.2 °C								
Dakota Pearl	68[1]	66 *a*[2]	70	70	57 *b*	58	64	62 *a*
ND7799c-1	69	68 *b*	70	70	62 *a*	59	63	55 *b*
ND7519-1	-	-	-	-	57 *b*	56	63	57 *b*
9.9 °C								
Dakota Pearl	68	69 *A*	72	70	57 *B*	62	65	63 *A*
ND7799c-1	69	71 *B*	72	70	62 *A*	61	66	62 *A*
ND7519-1	-	-	-	-	57 *B*	61	63	54 *B*

[1] Data points were not compared statistically across different temperatures

[2] Data points in the same column and temperature range were analyzed using the same model, and when followed by the same letter within a column are not significantly different according to Tukey pair-wise comparison at P = 0.05

2.6. Conclusion

The data collected and analyzed from this experiment suggests that for non-irrigated chip production in North Dakota growers could use similar agronomic management practices when growing ND7799C-1 and ND7519-1 compared to a current industry standard, Dakota Pearl, and expect similar yield and chipping quality. Within-row spacing of plants does appear to effect marketable yield in non-irrigated conditions, taking this into account proper agronomic practices should be followed to maximize marketable yield potential of the cultivars being grown.

Nitrogen rate data from this study suggests that growing the chipping selections at 90 kg ha^{-1} can reduce fertilizer expenses, prevent N leaching into the environment and eliminate potential storage or chipping quality issues. Applying N at this lower rate for the non-irrigated farms in the Red River Valley of North Dakota, appears to have no effect on yield or tuber quality in our study. Future research is warranted to identify the lowest nitrogen threshold while still maintaining similar yield and size profiles while not affecting overall chipping quality.

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