Effect of planting density and fertilization on yield and tuber characteristics of potato of Group Andigenum

Efecto de la densidad de siembra y la fertilización en el rendimiento y las características de tubérculos de papa del grupo Andigenum

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ABSTRACT

Fertilization and planting density are important practices in potato-producing regions, particularly in regions where yields are not optimal. In addition, appropriate characteristics are required for industrial processing of potato, prompting farmers to improve their productivity and produce varieties demanded by the agroindustrial market. The aim of this study was to determine the effect of two planting densities: 0.20 m x 1.00 m (50,000 plants ha^{-1}) and 0.40 m x 1.00 m (25,000 plants ha^{-1}) and three NPK fertilization doses (60-60-60, 120-120-120, 180-180-180) on the yield and tuber characteristics of potato (*Solanum tuberosum* Group Andigenum) varieties Serranita, Luyanita, and Capiro. A randomized block design was used with subdivided plots and three replicates. The results indicate higher total yield and commercial yield (42.87 and 38.74 t ha^{-1}) with the 180-180-180 kg ha^{-1} dose of NPK. The Luyanita variety stood out with yields of 36.03 and 30.97 t ha^{-1} of total and commercial tuber yield, respectively. The highest total and commercial tuber yields were obtained with the density 0.20 m x 1.00 m. The Luyanita variety showed acceptable physicochemical characteristics for agribusiness with 24.73% dry matter, low content of reducing sugars (0.21%), acceptable color of fries (3.11), specific gravity (1.11 g cm^{-3}) and adequate oil content (20.44%). The planting density factor showed no statistically significant differences.

Key words: varieties, *Solanum tuberosum*, soil, fertility.

RESUMEN

La fertilización y densidad de siembra son las prácticas más importantes en zonas productoras de papa, en las cuales los rendimientos no son óptimos; además se requiere de características apropiadas de los tubérculos para procesos industriales. Por lo tanto, los agricultores quieren mejorar su productividad y producir variedades que exige el mercado agroindustrial. El objetivo de este estudio fue determinar el efecto de dos densidades de siembra: 0.20 m x 1.00 m (50 000 plantas ha^{-1}) y 0.40 m x 1.00 m (25 000 plantas ha^{-1}) y tres dosis de fertilización NPK (60-60-60, 120-120-120, 180-180-180), en el rendimiento y características de los tubérculos de papa (*Solanum tuberosum* grupo Andigenum) de las variedades Serranita, Luyanita y Capiro. Se utilizó un diseño de bloques al azar con parcelas subdivididas y tres repeticiones. Los resultados indican mayor rendimiento total y rendimiento comercial (42.87 y 38.74 t ha^{-1}) con la dosis de NPK de 180-180-180 kg ha^{-1}. Se destacó la variedad Luyanita con rendimientos de 36.03 y 30.97 t ha^{-1} de rendimiento total y comercial de tubérculos. El mayor rendimiento total y comercial de tubérculos se obtuvo con la densidad 0.20 m x 1.00 m. La variedad Luyanita presentó características de tubérculos aceptables para la agroindustria debido a 24.73% de materia seca, bajo contenido de azúcares reductores (0.21%), color de fritura aceptable (3.11), gravedad específica (1.11 g cm^{-3}) y contenido de aceite (20.44%) adecuados. Para el factor densidad de siembra, no hubo diferencias estadísticamente significativas.

Palabras clave: variedades, *Solanum tuberosum,* suelo, fertilidad.

Introduction

In 2022, potato production in Peru reached 6.0 million t across nineteen departments of Peru, with 340.9 thousand ha of harvested area and an average yield of 17.6 t ha^{-1} (MIDAGRI, 2023). The average consumption of potatoes per person was 63.5 kg per year (INEI, 2023). In the highlands, approximately 68% of agricultural soils are affected by erosion processes of medium to extreme severity due to the lack of management techniques and the destruction of vegetation cover on the slopes. Most soils are predominantly stony, with rock outcrops on the slopes, that is, lithosols (Brack & Mendiola, 2000; Paulet Iturri & Amat León, 1999). Potato crop yield is often limited due to

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low and unbalanced rates of inorganic fertilizers and inadequate row and plant spacing (Tadesse & Mulugeta, 2023).

Fertilization and planting density are important practices in potato-producing areas, as they impact the yield and quality of the tubers (Flores-López *et al*., 2020; Pinedo-Taco *et al*., 2020). A positive correlation has been found between yield and different levels of fertilization in the potato, indicating that as yield per hectare grows, nutrient extraction by the plants also increases linearly (Oliver Cortez, 2017). Cheng *et al*. (2023) demonstrated that a high fertilization rate improved nutrient absorption, plant growth, and yield of potato tubers. In relation to planting density, Flores-López *et al*. (2016) obtained higher potato tuber yields when a higher density was applied.

In Peru, the average yield of potato production per unit area (17.6 t ha^{-1}) is not optimal (MIDAGRI, 2023). The industrialization of potatoes and the availability of varieties Serranita, Luyanita, and Capiro, which have potential industrial use, is a technological production opportunity for growers. It is necessary to increase productive yields while ensuring the following characteristics of tuber quality: dry matter content (≥ 20%), low content of reducing sugars (glucose and fructose) -preferably less than 0.25%, high specific weight (≥ 1.080 g cm^{-3}) and optimal size, shape, and presence of sprouts. These parameters are influenced by genotype, mineral nutrition, production environment, and storage conditions of the tubers (Casagrande *et al*., 2014; Tirado-Lara *et al*., 2020; Vásquez *et al*., 2019; Vázquez-Carrillo *et al*., 2016). Therefore, the aim of this study was to determine the effect of two planting densities and three doses of NPK fertilization on the yield and physicochemical characteristics of three potato varieties of Group Andigenum under the conditions of the northern highlands of Peru.

Materials and methods

The potato varieties evaluated were Serranita (V1), Luyanita (V2), and Capiro (V3) from the Instituto Nacional de Innovación Agraria (INIA), Estación Experimental Baños del Inca, Cajamarca (Peru).

The experiment was conducted in the town of Santa Rosa de Chaquil, located in the District of La Encañada, province of Cajamarca, Peru, at 2980 m a.s.l., with coordinates 07°07'78" S and 78°19'59.3" W, average temperature of 16.6°C, and annual rainfall of 674.4 mm (SENAMHI, 2022). The soil is characterized by a sandy loam texture. Planting took place on November 20, 2020 and tubers were harvested during the months of April and May 2021 after growing periods of 140, 150, and 165 d for Luyanita, Serranita, and Capiro, respectively.

The soil characteristics were: pH 4.8, organic matter contents 2.10% (medium), phosphorus contents 30.52 mg kg^{-1} (high) and potassium 220.0 mg kg^{-1} (high) (INIA, EAA Baños del Inca, Cajamarca, 2022).

Eighteen treatments were carried out with three doses of N-P-K fertilizers (low (F1) =60-60-60, medium (F2) =120-120-120 and high (F3) =180-180-180)), with two planting densities: d1= 1.0 m x 0.20 m (50,000 plants ha^{-1}); d2= 1.0 m x 0.40 m (25,000 plants ha^{-1}), and three potato varieties (V1= Serranita, V2= Luyanita, V3 = Capiro. The percentage of dry matter in tubers was determined by the method recommended by Bonierbale *et al.* (2010). This consisted of taking approximately 500 g of small tuber fractions of 1 to 2 cm, mixing them thoroughly and taking sub-samples of 200 g each. The exact weight of each subsample was recorded and each subsample was then placed in a paper bag or open container in the oven at 80°C for 72 h, checking the weight of the samples at regular intervals until they reached a constant weight. Finally, the percentage of dry matter content of each subsample was calculated using the following equation:

$$Dry\ matter = \frac{dry\ weight}{fresh\ weight} \times 100\% \qquad \text{(Eq. 1)}$$

The amount of reducing sugars in the 200 g samples was evaluated using the 3,5-dinitrosalicylic acid (DNS) method. The content of reducing sugars was calculated using the following equation:

$$\%\ RS = \frac{(Abs\text{-}B)\text{-}a}{b \times M} \times 100\% \qquad \text{(Eq. 2)}$$

where % RS: percentage of reducing sugars; Abs: sample absorbance; B: blank sample absorbance; M: sample fresh weight (g); a is an intercept of the calibration curve; b is a slope of the calibration curve.

The color of the fries was evaluated using the color chart recommended by the International Potato Center (Bonierbale *et al*., 2010), with a scale from 1 to 5, where 1 is an acceptable yellow color and 5 is a very dark yellow or brown color.

Determination of specific gravity (SG) was done using the weight-in-air/weight-in-water method recommended by Bonierbale *et al.* (2010). The specific gravity was obtained using the equation:

$$Specific\ gravity = \frac{weight\ in\ air}{weight\ in\ air\text{-}weight\ in\ water} \quad \text{(Eq. 3)}$$

To determine the oil content in tubers of potato varieties for frying and production and the degree of oil absorption, the pressure method was used according to Bonierbale *et al*. (2010).

The experimental design was in randomized complete blocks, with subdivided plots and three replicates, where the large plot based on was two densities (d1, d2), the intermediate plot on three levels of fertilization (F1, F2, and F3), and the small plot on the potato variety factor (V1, V2, and V3). The distance between rows was 1.00 m and the distance between plants was 0.20 and 0.40 m. The furrow length was 3.0 m. Fertilization was carried out in a continuous jet with 50% N and 100% P and K at planting. Nitrogen source was urea 46%; phosphorus source was simple calcium superphosphate 20%; and potassium source was potassium chloride 60%. Application doses were 50% N plus 100% P and K at sowing, and the remaining 50% of N during the potato tuber filling.

During the harvest phase, total yield, commercial yield, and non-commercial yield of tubers were evaluated. The commercial yield of tubers was evaluated according to the Colombian classification by diameter (Arias *et al*., 1996; Bautista *et al*., 2012; Escallón *et al*., 2005; Rodríguez *et al*., 2009) as cited by Seminario *et al*. (2018). The classification considered the following three size categories: first class > 4 cm, second class 2-4 cm, and third class <2 cm. Commercial yield consisted of first-class and second-class tubers. Commercial yield met quality conditions for sale, while non-commercial yield did not meet these conditions.

For the evaluation of other variables, 20 tubers were taken per treatment and sent to the International Potato Center (Lima, Peru) for analysis of frying quality, dry matter content, oil extraction, and specific gravity.

Statistical analysis

The data was analyzed using Statistical Analysis Systems (SAS Institute, 2004). The assumptions of homogeneity (Barlett's test) and the normality of variance (Shapiro-Wilk test) were validated, followed by a one-way ANOVA. The treatment comparisons were carried out using the least significant difference (LSD) test ($P<0.01$).

Results and discussion

According to the analysis of variance for total yield, commercial yield, and non-commercial yield of tubers of the three varieties, highly significant differences ($P\leq0.01$) were found for the factors of fertilization (F) and varieties (V) in all yield categories. This indicates that the different levels of these factors affected the yield, except in the case of planting density, with no statistically significant differences detected ($P>0.01$) (Tab. 1).

TABLE 1. Analysis of variance in the study of planting densities and fertilization levels in three potato (*Solanum tuberosum* Group Andigenum) varieties Serranita, Luyanita, and Capiro.

Source of variation	Degrees of freedom	Yield		
		Total	Commercial	Non-commercial
Replicates	3	ns	ns	ns
Density (D)	1	ns	ns	ns
Error (a)	3			
Fertilization (F)	2	**	**	**
DxF	2	ns	ns	ns
Error (b)	12			
Varieties (V)	2	**	**	**
DxV	2	ns	ns	ns
FxV	4	ns	ns	ns
DxFxV	4	ns	ns	ns
Error (c)				
Total	71			
Variation coefficient		16.10%	16.96%	35.06%

**$P\leq0.01$; ns: not significant.

These results show that there is genetic variability between the varieties evaluated and that each level of NPK fertilization elicits a different response in yields. The coefficient of variability (CV) used as a measure of accuracy in conducting experiments (Vásquez-Arce, 2014) for total tuber yield and commercial yield was 16.1% and 16.96%, respectively, indicating the accuracy of the experiment. The coefficient of variation for non-commercial yield was 35.06%, considered high (Gordón-Mendoza & Camargo-Buitrago, 2015). When comparing the means of the fertilization factor, a significant difference was identified in the three levels (Fig. 1), with the highest level of fertilization, 180-180-180 kg NPK ha^{-1}, achieving total and commercial yields of 42.87 t ha^{-1} and 38.74 t ha^{-1}, respectively, and a non-commercial yield of 4.74 t ha^{-1}.

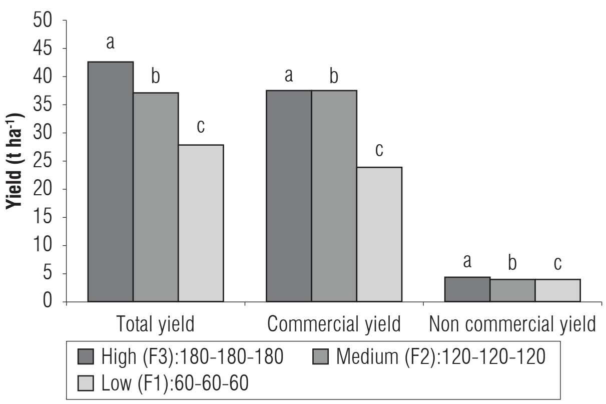

FIGURE 1. Averages of total, commercial and non-commercial yields in three varieties of potato (*Solanum tuberosum* Group Andigenum) Serranita, Luyanita, and Capiro at two planting densities and three levels of fertilization. Different letters indicate significant differences according to the LSD test ($P \leq 0.01$).

The average yields for increasing fertilizer doses – low (60 kg ha^{-1} of NPK), average (120 kg ha^{-1} NPK) and high (180 kg ha^{-1} NPK) – were 28.31, 37.53, and 42.87 t ha^{-1}, respectively; for commercial yields the averages were 24.10, 32.79, and 38.74 t ha^{-1}, which indicates an upward trend, that is to say, the higher the fertilizer dose, the higher the productivity (Fig. 1). The results are consistent with those of Flores-López *et al.* (2020), Ríos Quinchoa *et al.* (2010), and Vega Cobos (2018), who found high tuber yields with the NPK fertilization levels studied (high and medium). In this regard, Jiang *et al.* (2021) found that increasing nitrogen application rates in two potato varieties improved both tuber yield and processing quality, with the optimal dose of N about 98-200 kg N ha^{-1} for yield and high quality of potato chips. However, Valverde Samekash and Bobadilla Rivera (2017) achieved lower yields (24.95 t ha^{-1}) with an NPK fertilization of 180-160-120. This low yield was probably due to the low potassium (K_2O) dose of 120 kg ha^{-1} since the potato is a species with a high response to the application of fertilizers due to its low root density (Campos, 2014). Furthermore, the potato crop extracts a high amount of potassium; for example, Westermann (2005) reported that a yield of 56 t ha^{-1} of potato corresponds to an extraction of 400 kg ha^{-1} of K_2O by the plants.

Figure 2 shows the yields of the three varieties, indicating that the Luyanita (V2) and Serranita (V1) had total yields of 36.03 and 34.05 t ha^{-1}, respectively, and 30.97 and 30.80 t ha^{-1} of commercial yield, respectively, but did not show statistical differences between them. Both varieties statistically outperformed the Capiro variety (V3), whose total and commercial yields were 22.48 t ha^{-1} and 19.05 t ha^{-1}.

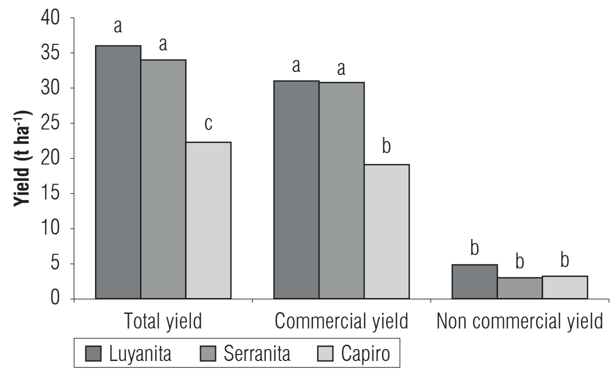

FIGURE 2. Averages of total, commercial and non-commercial yields in three varieties of potato (*Solanum tuberosum* Group Andigenum) Serranita, Luyanita, and Capiro at two planting densities and three levels of fertilization. Different letters indicate significant differences according to LSD ($P \leq 0.01$).

Yields of the Serranita variety (34.05 t ha^{-1}) are lower than those reported by Cárdenas Huamán (2018), who in a comparative study of five varieties from sexual seed obtained a yield of 35.0 t ha$^{-1.}$ The difference may be due to greater uniformity in plant growth, which leads to a better distribution of nutrients, water and light, resulting in a higher yield. The Capiro variety reached average yields of 22.48, 19.05, and 3.43 t ha^{-1} (Fig. 2). Commercial yields of the Luyanita and Serranita varieties (30.87 and 30.80 t ha^{-1}) were lower than those reported by Tirado-Lara *et al.* (2020), who achieved commercial yields of 31.8, 32.0, and 33.0 t ha^{-1} in advanced potato genotypes with pigmented pulp. The high yield obtained by the varieties under study is consistent with the reports of Morales *et al.* (2013), who obtained a high response with doses of 150-250-70 kg of N-P-K.

For the planting density of 0.20 m x 1.00 m, the highest total yield of 31.25 t ha^{-1} was achieved, with a commercial yield of 27.14 t ha^{-1} and a non-commercial yield of tubers of

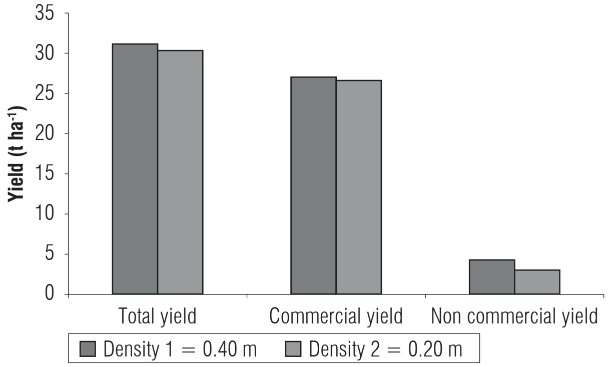

FIGURE 3. Averages of total, commercial and non-commercial yields in three potato varieties (*Solanum tuberosum* Group Andigenum) Serranita, Luyanita, and Capiro at two planting densities and three levels of fertilization. For each yield category, no significant differences were found between the planting densities (LSD, $P>0.05$).

4.50 t ha^{-1} (Fig. 3). These results are consistent with Vargas *et al*. (2021) who found that the higher planting density favored an increase of approximately 17% in tuber yield in the potato cultivars evaluated. Valverde and Bobadilla (2017) found that a density of 1.0 m x 0.20 m achieved a 24.95 t ha^{-1} yield, while a decreased density (1.0 m x 0.40 m) reduced yield to 13.2 t ha^{-1}. Vega (2018) stated that the highest commercial yield was obtained with a density of 0.40 m x 0.90 m, and Almeida *et al*. (2016.) achieved a yield of 16.34 t ha^{-1} with spacing of 0.90 m x 0.30 m. These reports confirm that potato plantations with relatively high densities give higher yields, as observed in the present research. Variations in yield can be attributed to the edaphoclimatic conditions (Alemeida *et al*., 2016). Our results surpassed those achieved by Rojas Mercado and Seminario Cunya (2014), who obtained yields of 5 to 11.0 t ha^{-1} with a planting density of 0.40 m x 0.90 m. However, our results were not in agreement with those obtained by Rodríguez *et al*. (2004), who had high yields with greater planting density. Likewise, the results obtained in the present experiment are not consistent with those found by Arismendi (2002), who obtained a higher tuber yield with a planting density of 0.20 m between plants. These different results are attributed to the phenotypic plasticity of the varieties studied in each case (Rodríguez *et al*., 2004). However, our results agree with the notion that higher fertilization leads to greater yield of potato tubers.

The results of the present experiment in terms of planting density differ from those of López Crus and Guevara Hoyos (2022), who obtained greater yield with a density of 0.30 m x 0.90 m. This confirms that high planting density in potato crop influences tuber yields due to its impact on the competition between plants (competitive ability), which impacts accumulation of dry matter and the use of soil and air space (Dogliotti *et al*., 2011; López Crus & Guevara Hoyos, 2022).

The variance analysis (Tab. 2) of the five physicochemical variables studied of tuber quality is interpreted considering them as a fixed effects model, as they are important for the processing industry.

In the source of variation for fertilization (F) and variety (V), there are highly significant differences ($P\leq0.01$) for dry matter, reducing sugars, color (C), and oil content, indicating statistical differences between fertilization levels and varieties (Tab. 2). There was no statistical difference

TABLE 2. Analysis of variance and statistical significance for the variables of tuber quality of three potato varieties grown at two planting densities and three doses of NPK fertilization.

Source of variation	Degrees of freedom	Dry matter	Reducing sugars	Color of the fries (C)	Specific gravity	Oil content
Repetitions	3	ns	ns	ns	ns	ns
Density (D)	1	ns	ns	ns	ns	ns
Error (a)	3					
Fertilization (F)	2	**	**	ns	ns	**
DxF	2	ns	ns	ns	Ns	ns
Error (b)	12					
Varieties	2	**	**	*	ns	**
DxV	2	ns	ns	ns	ns	ns
FxV	4	ns	ns	ns	ns	ns
DxFxV	4	ns	ns	ns	ns	ns
Error (c)	36					
Total	71					
Variation coefficient		9.5%	6.6%	18.8%	1.2%	7.5%

** Significant ($P<0.01$); ns: not significant.

for the source of variation of density (D). These results are not consistent with those obtained by Almeida *et al.* (2016), who found statistical significance for the different distances between potato plants. This result was due to the fact that they tested extreme distances between plants (15, 20, 25, or 30 cm) and 90 cm between rows. The coefficients of variation for the evaluated variables ranged from 1.2% to 18.8%, revealing the good experimental accuracy of this evaluation methodology. Table 3 presents the comparison of LSD averages for dry matter (DM), reducing sugars (RS), color (C), specific gravity (SG) and oil content (OC) evaluated in tubers of three potato varieties under the effect of two planting densities and three levels of fertilization.

The variation between varieties (Tab. 3), for dry matter (DM), reducing sugars (RS), color (C) and oil content (OC), especially in the behavior of the three varieties, Serranita (V1), Luyanita (V2) and Capiro (V3), suggests that they can be selected by their values obtained for each variable studied.

For dry matter (DM), the multiple comparison ranges of LSD at 5% probability (Tab. 3) showed that the average dry matter content of the Serranita variety (22.53%) was statistically similar to that obtained for the Capiro variety (22.24%). The Luyanita variety stood out (24.73%), statistically surpassing Serranita and Capiro. This variation is due to several factors, such as sowing date, soil moisture content, harvest time, and physiological age of the tubers, among others, all of which influence the different potato genotypes. These factors contribute to increasing the variability of dry matter content from one season to another due to their high heritability (Vásquez-Carrillo *et al.*, 2016). The 24.73% dry matter percentage of Luyanita exceeds the results of Silveira *et al.* (2020), who characterized 25 potato clones and obtained values between 17.19 and 23.5% dry matter; as well as those of Aliaga *et al.* (2016) who obtained 22.5% dry matter with the Capiro variety. Therefore, the Luyanita variety would be considered the most suitable for the processing industry since, according to Ticsihua Huamán *et al.* (2021), the tubers used for the production of fried flakes must have a dry matter content higher than 20%.

For reducing sugars (RS), the comparison of the means of the three varieties (Tab. 3) indicates that the Serranita variety had an average of 0.28%, surpassing the Luyanita and Capiro varieties with values of 0.21% and 0.22%, respectively. These results are lower than those reported by Aliaga *et al.* (2016), who found values of 0.288% to 0.466% with the Capiro variety cultivated at soil pH of 4.8 to 7.1, respectively. However, they are not consistent with those of Vázquez-Carrillo *et al.* (2016), who evaluated six genotypes at altitudes of 2,600 m a.s.l. and 3,500 m a.s.l. and found values of 0.04% to 0.58%.

Considering that the three varieties evaluated in this trial had the same growing conditions, these differences are likely due to a varietal (genetic) factors. It is possible that these varieties have different development cycles (150 d for Serranita, 140 d for Luyanita and 165 d for Capiro), which could affect the level of reducing sugars during the time of harvest as a result of the interaction with the environment (Morales-Fernández *et al.*, 2018; Moreta Villacrés, 2021; Tirado-Lara *et al.*, 2020). This indicates that for good frying quality, reducing sugars of 0.20% and 0.30% are recommended. Our results are consistent with these reports, since the variation shown in sugar content between

TABLE 3. Comparison of means (LSD) of variables evaluated in tubers of three potato varieties with three levels of fertilization and two planting densities.

Fertilization	Variables				
	Dry matter (%)	Reducing sugars (%)	Color of the fries	Specific gravity	Oil content (%)
High (F3): 180-180-180	24.59 a	0.36 a	2.92 a	1.080	24.8 b
Medium (F2): 120-120-120	22.42 b	0.35 a	2.77 b	1.100	27.0 a
Low (F1): 60-60-60	20.50 b	0.25 b	2.61 b	1.110	27.2 a
Variety					
Serranita (V1)	22.53 b	0.28 a	2.84 a	1.090	27.30 a
Luyanita (V2)	24.73 a	0.21 b	3.11 a	1.110	20.44 b
Capiro (V3)	20.24 b	0.22 b	2.35 b	1.080	27.30 a
Density					
D1 (1.0 m x 0.20 m)	33.57	0.92	2.01	1.47	39.80
D2 (1.0 m x 0.40 m)	33.94	0.42	2.29	1.10	39.20

Treatments with the same letter do not differ significantly according to the 5% LSD test.

varieties reflects their ability to accumulate carbohydrates in tubers during crop development.

The multiple comparison test of LSD showed that the average percentage of reducing sugars corresponding to the Luyanita variety (0.21%) was statistically lower than those obtained by the Serranita (0.28%) and Capiro (0.22%) varieties, making Luyanita and Capiro suitable for frying due to the low content of reducing sugars. This characteristic is directly responsible for the adequate or inadequate coloration of the product after frying (Tab. 3). Palermo *et al.* (2016) indicated that varieties with a lower content of reducing sugars are associated with a lower production of acrylamide during frying. They recommend using varieties with a content of reducing sugars less than 0.30% of fresh weight, since values greater than 0.33% are unacceptable for frying.

For frying quality, no statistical differences were obtained between the Serranita and Luyanita varieties, whose averages for color of the fries were 2.84 and 3.11, respectively, which according to the CIP scale correspond to the creamy yellow color with low presence of dark spots, surpassing the average obtained by the Capiro variety, which had a value of 2.35 (white or creamy yellow) (Bonierbale *et al.*, 2010) (Tab. 3). The color of the fries is a very important variable in tuber quality and largely depends on the reducing sugar content, since a lower content of sugars produces a lighter frying color, making it acceptable for the industrialization and commercialization of French fries (Ticsihua Huamán *et al.*, 2021).

The cultivars Serranita and Capiro had the most acceptable color of fries of 2.35 to 2.84, due to their low values on the scale of the Bonierbale *et al.* (2010), as a result of their lower content of reducing sugars (Tab. 3). This suggests that the three varieties have the best frying quality, as they presented the best processing characteristics in this study. These results are not consistent with those obtained by Tirado-Lara *et al.* (2020), who achieved values of 1.7 to 3.5 on the CIP scale when evaluating frying quality of improved pigmented pulp genotypes.

The specific gravity (SG) values were 1.090, 1.110 and 1.080 for Serranita, Luyanita, and Capiro, respectively (Tab. 3). No statistical differences were found between the specific gravity values. These results are higher than those reported by Alcon Callejas and Bonifacio (2020), who, in trials with bitter potato varieties, found values between 1.002 and 1.040. However, they are similar to those obtained by Silveira *et al.* (2020). When evaluating 25 potato clones, they found values ranging from 1.050 to 1.110, indicating that they are suitable for the potato chip industry.

According to Lizarazo *et al.* (2022), specific gravity is influenced by variety and environmental conditions such as soil type, water availability, and soil fertility. The three varieties were grown in the same place and under the same conditions, so the differences between them in this variable are due to the variety interaction with the environment (Vásquez *et al.*, 2019).

It can be inferred that the varieties evaluated are suitable for agribusiness, as the Bonierbale *et al.* (2010) recommends specific gravity values between 1.09 and 1.11. Likewise, the variables of specific gravity and dry matter evaluated (Tab. 3) show a high and positive correlation (r = 0.979). This is consistent with the reports of Alcon Callejas and Bonifacio (2020) and Silveira *et al.* (2020).

For oil content (OC), there were no statistical differences between the Serranita and Capiro varieties, whose average was 27.30%, surpassing the Luyanita variety with an average of 20.44%. This indicates that the Luyanita variety had lower oil absorption (Tab. 3). These results are lower than those reported by Mora (2016), who obtained 28.8% to 31.5% and those of Valencia-Flórez *et al.* (2017), who reported averages of 27.8 to 29.5%, respectively. For the Serranita variety, Espitia Sotelo and Soto Sáenz (2015) obtained an average oil content of 17.62%, well below the varieties studied in this experiment. These reports indicate that these percentages are obtained if they are not subjected to any pre-frying treatment.

The higher dry matter content (≥24.73%), which corresponds to a higher specific gravity (≥1.110) and low level of reducing sugars (≤0.21), results in lower oil absorption in the frying process (20.44%) (Tab. 3). These results are consistent with Silveira *et al.* (2020), who stated that potatoes with higher dry matter content (≥20%) and higher specific gravity (≥1.080) with low levels of reducing sugars result in fried foods with lower oil content. These data imply that the Luyanita variety (Fig. 2 and Tab. 3) is ideal for industrial processing.

The fertilizer doses affected dry matter content, reducing sugars, color, and oil content (Tab. 3). Dry matter values were higher (24.59%) with the high fertilization rate (180-180-180), statistically surpassing the medium and low doses, whose averages were 22.42% and 20.50% respectively. With low NPK applications (60-60-60 kg ha^{-1}), low values of reducing sugars (0.25%), color (2.61) and specific gravity

(1.110) were obtained, which are suitable for processing (Tab. 3), indicating that this low level of NPK favors the improvement in product quality.

These results are consistent with Palacios *et al*. (2008), who found an improvement of the terminal product, such as chips and canes, with low levels of fertilization. However, these results are not consistent with those reported by Giletto *et al*. (2013), who found lower dry matter content (19%) when N-P-K fertilization levels increased. It was observed that the content of dry matter, reducing sugars, specific gravity and color decreased with low NPK doses (Tab. 3).

Regarding specific gravity, there were no statistical differences for the three fertilization doses (Tab. 3), which indicates that fertilization did not influence this variable, with averages ranging 1.080 to 1.110. The lowest specific gravity, 1.080 was obtained with the formula 180-180-180 NPK kg ha^{-1}, indicating an inverse relationship. These results are consistent with those of Ozturk *et al*. (2010), who stated that the specific gravity of the potato decreases with increasing levels of NPK. They also conform to Rivera *et al*. (2006) who established that for potatoes to be suitable for chips, the specific gravity must be greater than 1.080. An upward trend was found between NPK fertilization levels and reducing sugar content (Tab. 3).

No significant differences were found for oil content between the 120-120-120 and 60-60-60 doses, with averages of 27.0 and 27.2%, respectively. However, at the 180-180-180 dose, the oil content was 24.8% (Tab. 3). This is consistent with Öztürk *et al*. (2010), who stated that the oil content decreases with increasing phosphorus levels. Based on the results obtained in this experiment, we recommend low applications of NPK (60-60-60 kg ha^{-1}) for potato producers whose production is destined for industrial processing, as this formulation helps to improve the quality of the final product (chips, sticks). Regarding the sowing density, there were no statistical differences for the variables of dry matter contents, reducing sugars, color, specific gravity, and oil content in tubers.

Conclusions

The results obtained suggest that high planting density and high doses of NPK fertilization in potato crop influenced the yield and physicochemical characteristics of the three varieties studied, with potential use for the industry. The superiority of the Luyanita potato variety over other varieties, in the conditions of the Cajamarca highlands (Peru), is marked by its higher yield and acceptable physicochemical properties for industrial processing. This achievement contributes to agricultural development, benefitting growers and the agro-industrial sector. It will be important to continue research on this topic, focusing on planting density with a wider spacing between rows and potato plants cultivated in different agroecological areas.

Conflict of interest statement

The authors declare that there is no conflict of interests regarding the publication of this article.

Author's contributions

VV and HC designed the experiments; VV, LJ and RP carried out the field and laboratory experiments; PH, VC and CC contributed to data analysis; PH and BA wrote the article. All authors reviewed the final version of the manuscript.

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