SCAP
SOCIEDADE DE CIÊNCIAS AGRÁRIAS DE PORTUGAL

Increasing nitrogen doses on the postharvest quality of green corn

Doses crescentes de nitrogênio na qualidade pós-colheita do milho verde

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A B S T R A C T

The effects of nitrogen (N) rates on the physicochemical attributes of green corn are still poorly understood. The objective of this study was to evaluate the influence of increasing N rates applied via fertigation on the postharvest quality of green corn grown under semi-arid conditions. The experiment was conducted in the field from January to April 2016 in Canindé de São Francisco, Sergipe, Brazil, using a randomized block design with four N rates (0, 80, 160, and 240 kg ha^{-1}) and four replications. The Bt Feroz hybrid was cultivated under localized irrigation with split fertigation of the N rates. After harvest at the R3 stage (milk stage), grain moisture, ash content, pH, acidity, and texture were determined. Data were subjected to analysis of variance and polynomial regression. The results indicated that only ash content showed a significant difference among N rates, fitting a quadratic model with an estimated maximum value of 0.76% at an N rate of 75 kg ha^{-1}. The other variables—moisture (62.16%), pH (6.85), acidity (2.17%), and texture (9.45 N)—were not significantly influenced by nitrogen fertigation.

Keywords: *Zea mays* L., nitrogen fertilization, fertigation, semi-arid

R E S U M O

Os efeitos das doses de nitrogênio (N) sobre os atributos físico-químicos do milho verde ainda não se encontram plenamente elucidados. Objetivou-se avaliar a influência de doses crescentes de N, aplicadas via fertirrigação, sobre a qualidade pós-colheita do milho verde cultivado em condições semiáridas. O experimento foi conduzido a campo, no período de janeiro a abril de 2016, no município de Canindé de São Francisco, Sergipe, Brasil, em delineamento em blocos casualizados, com quatro doses de N (0, 80, 160 e 240 kg ha^{-1}) e quatro repetições. Utilizou-se o híbrido Bt Feroz, cultivado sob irrigação localizada, com aplicação parcelada das doses de N via fertirrigação. Após a colheita no estádio fenológico R3 (grão leitoso), foram avaliados o teor de umidade dos grãos, o teor de cinzas, o pH, a acidez titulável e a textura. Os dados foram submetidos à análise de variância e à análise de regressão polinomial. Os resultados indicaram que apenas o teor de cinzas foi significativamente influenciado pelas doses de N, ajustando-se a um modelo quadrático, com valor máximo estimado de 0,76% na dose de 75 kg ha^{-1} de N. As demais variáveis — umidade (62,16%), pH (6,85), acidez titulável (2,17%) e textura (9,45 N) — não apresentaram efeito significativo da fertirrigação nitrogenada.

Palavras-chave: *Zea mays* L., fertilização nitrogenada, fertirrigação, semiárido

INTRODUCTION

Corn (*Zea mays* L.) is one of the main agricultural crops in Brazil, occupying a prominent position in both human and animal nutrition as well as serving as a raw material for various industries. Green corn, in particular, has high socioeconomic importance due to its fresh consumption, either as boiled or roasted ears, or as an ingredient in traditional Brazilian dishes (such as *pamonha*, *curau*, and cakes). In addition to its commercial value, green corn represents an alternative source of income for small and medium-sized farmers in several regions of the country (Batista *et al*., 2022).

Fertilization is one of the main factors influencing corn productivity and quality. Among nutrients, nitrogen (N) is the most demanded by the crop, playing key roles in growth, development, and protein accumulation in the grains (Wang *et al*., 2018). Inadequate N management can result in nutritional deficiencies, reducing productivity and quality, as well as in excesses that increase production costs and raise environmental risks, particularly losses through volatilization and leaching (Delgado *et al*., 2024; Galindo *et al*., 2024; Sharma *et al*., 2024; Singh & Prasad, 2024).

Most research on nitrogen fertilization in corn focuses on dry grain yield, silage, or green ear production, with little emphasis on how N affects the quality and preservation of green corn after harvest (Batista *et al*., 2022). This aspect is relevant because consumer acceptance and product shelf life are directly related to physicochemical parameters such as moisture, pH, acidity, inorganic residue (mineral content), and grain texture (Gao *et al*., 2021; Singh *et al*., 2024; Jiang *et al*., 2025).

Each of these attributes reflects different aspects of the composition and physiological state of the product. Moisture content is associated with the maturity stage and freshness of the ears and is a determining factor for grain texture and juiciness. pH reflects chemical balance and the product's preservation potential, while inorganic mineral residue indicates the efficiency of nutrient absorption and translocation. Texture, in turn, is an essential sensory parameter directly related to consumer acceptance of green corn (Correndo *et al*., 2021; Li *et al*., 2021; Zhang *et al*., 2021).

Therefore, understanding the effects of N rates on the postharvest quality of green corn is essential to integrate productivity and quality, providing technical information that helps farmers and agro-industries better meet market demands (Galindo *et al*., 2024; Wang *et al*., 2018).

In this context, the present study aimed to evaluate the influence of increasing N rates applied via fertigation on the physicochemical characteristics of green corn, seeking to identify the N rate that provides the best product quality under the edaphoclimatic conditions of the municipality of Canindé de São Francisco, Sergipe, Brazil.

MATERIALS AND METHODS

The experiment was conducted under field conditions from January to April 2016 on a farm located within an irrigated perimeter supplied with water from the São Francisco River, in the municipality of Canindé de São Francisco, Sergipe, in the Brazilian semi-arid region (9°40′27″ S, 37°45′45″ W, 194 m altitude). According to the Köppen climate classification, the regional climate is Bssh′, very hot semi-arid steppe, with a rainy season concentrated in the months of April, May, and June. Mean meteorological data for the experimental period were obtained from an automatic weather station located 6 km from the experimental area (Figure 1).

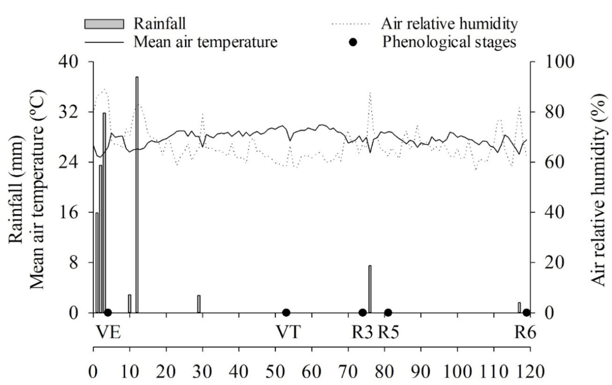

Figure 1 - Accumulated rainfall, mean air temperature, relative air humidity, and indication of phenological stages (VE: emergence; VT: tasseling; R3: milk stage; R5: dough stage; R6: physiological maturity) of corn fertigated with nitrogen rates for green ears, during the 2016 summer growing season in Canindé de São Francisco, Sergipe, Brazilian semi-arid region.

The soil of the experimental area was classified as a Chromic Luvisol, according to the Brazilian Soil Classification System (Embrapa-Solos, 2018), with undulating topography and clayey texture, presenting particle-size values of 478.20 g kg^{-1} of sand, 98.00 g kg^{-1} of silt, and 423.80 g kg^{-1} of clay. The soil chemical characteristics are described in Table 1.

Table 1 - Chemical analysis of the soil in the experimental area cultivated with corn for green ears (0–20 cm depth), during the 2016 summer growing season in Canindé de São Francisco, Sergipe, Brazilian semi-arid region

P	K^+	Ca^{2+}	Mg^{2+}	Na^+	Al^{3+}	H+Al
mg dm^{-3}	---------------------------cmol$_c$ dm^{-3}---------------------------					
24.00	0.37	16.30	10.10	0.12	0.00	3.20
pH	**EC***	**OM***	**Cu**	**Fe**	**Mn**	**Zn**
H_2O	dS m^{-1}	g kg^{-1}	---------------mg dm^{-3}---------------			
6.60	0.34	25.80	0.10	42.90	76.60	2.00

EC* = electrical conductivity; OM = organic matter. P, K^+, and Na+: Mehlich extractant (HCl + H_2SO_4); Ca^{2+}, Mg^{2+}, and Al^{3+}: 1 M KCl.

The experimental design adopted was a randomized block design with four replications. Treatments consisted of four N rates (0, 80, 160, and 240 kg ha^{-1}). Nitrogen fertilization was split, with 15% of the N rate applied at 15 days after emergence (DAE), 50% at 20 DAE, and 35% at 40 DAE, using a Venturi-type fertilizer injector. A constant zinc rate (2.0 kg ha^{-1}) was applied via fertigation to all treatments (Sobral *et al.*, 2007). Nitrogen and Zn were supplied through urea and zinc sulfate fertilizers, respectively.

Each plot consisted of six rows 6 m in length, spaced 1 m apart, totaling an area of 36 m^2 (6 m × 6 m). The four central rows, excluding 0.20 m from each end, were considered the usable plot area (22.4 m^2).

Soil preparation consisted of two cross harrowings to an average depth of 20 cm. Subsequently, plots were marked and sowing was carried out manually using the Bt Feroz corn hybrid (Syngenta®) at a spacing of 1.0 m × 0.2 m (50,000 plants ha^{-1}), with planting performed on January 20, 2016. This cultivar is a double-cross hybrid with an early cycle and hard, orange-colored grains.

The experiment used a localized drip irrigation system, with 0.2 m spacing between emitters and an average flow rate of 1.2 L h^{-1}. The irrigation depth was determined by water balance, considering rainfall and crop evapotranspiration (ETc). The total gross irrigation depth amounted to 204 mm.

Crop management practices followed the standard procedures used by local farmers. Weed control was performed by applying the herbicide atrazine (500 g L^{-1}) at 23 DAE.

Harvests were carried out at the R3 phenological stage, corresponding to 66 DAE, which represents the consumption point for fresh market green ears. Marketable husked ears were defined as those with adequate appearance for commercialization, i.e., without visible pest damage and with a length greater than 19 cm.

After harvesting each plot, grains from ten ears within the usable area were separated and analyzed in triplicate at the Food Analysis Laboratory of the Federal Institute of Alagoas (IFAL), Piranhas Campus, following methodologies described by the Adolfo Lutz Institute (IAL, 2008) and available laboratory protocols. The following variables were evaluated: moisture content (% wet basis), determined by oven-drying at 105 °C until constant weight; ash content (%), obtained by incineration in a muffle furnace at 550 °C until white or grayish ash was achieved; pH, measured directly in homogenized pulp using a digital potentiometer; titratable acidity (% malic acid), determined by titration with 0.1 mol L^{-1} NaOH using 1% alcoholic phenolphthalein solution as an indicator; and texture (firmness, Newton – N), determined using a TA.XT Express Enhanced texture analyzer with a 5 mm probe, measured on opposite sides of the equatorial region of the grains.

After verifying normality and homoscedasticity, data were subjected to analysis of variance (ANOVA) using the randomized block design. When a significant effect of N rates was identified, polynomial regression equations were fitted, considering the highest coefficients of determination and the significance of the terms. Statistical significance was set at 5% probability ($p < 0.05$).

RESULTS AND DISCUSSION

Grain moisture content of green corn did not show a significant difference among the applied nitrogen rates (Table 2), with an overall mean of 62.16%, a value consistent with the typical range for corn harvested at the milk stage, between 60% and 70%. Recent studies corroborate these results, indicating that increasing nitrogen rates, even across a wide range, tend to promote small and statistically non-significant differences in grain moisture content (Zhang *et al.*, 2021). The literature indicates that moisture is strongly influenced by the stage of maturity and by climatic conditions at harvest, such as temperature and relative air humidity, which play a determining role in water retention (Gao *et al.*, 2021; Li *et al.*, 2021; Zhang *et al.*, 2025).

Table 2 - Summary of the analysis of variance (F values) for moisture, ash content, pH, acidity, and texture of green corn fertigated with nitrogen (N) rates in the municipality of Canindé de São Francisco, Sergipe, Brazil

Source of variation	DF	Moisture (% w.b.)	Ash (%)	pH	Titratable acidity (% malic acid)	Texture (N)
N rates	3	1.05 ^{ns}	5.40*	1.14 ^{ns}	0.45 ns	1.09 ^{ns}
Blocks	3	0.57 ^{ns}	1.12 ^{ns}	1.30 ^{ns}	0.75 ^{ns}	1.68 ^{ns}
CV (%)		7.79	4.34	1.32	25.22	11.06
Overall mean		62.16	0.73	6.85	2.17	9.45

* and ^{ns}: significant and non-significant at 5% probability by the F test, respectively; DF*: degrees of freedom; CV: coefficient of variation.

Additionally, recent analyses of variance have shown that, although genetic effects and genotype × environment interactions exist, the physiological stage and the growing environment explain most of the variation in grain moisture, whereas the influence of nitrogen fertilization is secondary (Li *et al.*, 2021; Zhang *et al.*, 2025). Thus, the absence of a significant nitrogen effect on moisture reinforces that nitrogen fertigation does not markedly alter water retention in the grains, confirming the predominance of environmental factors and harvest timing over mineral nutrition in determining this attribute (Gao *et al.*, 2021; Li *et al.*, 2021; Zhang *et al.*, 2021, 2025).

In contrast, ash content of corn grains showed a significant difference among N rates (Table 2), with an overall mean of 0.73%, indicating that nitrogen fertilization influenced the mineral content of the grains. Ash content values fitted a quadratic model, with a maximum of 0.76% at an N rate of 75 kg ha^{-1} (Figure 2). This effect may be attributed to increased absorption and translocation of nutrients such as calcium, potassium, and phosphorus, favored by adequate nitrogen supply (Singh *et al.*, 2023, 2024; Daroga *et al.*, 2022).

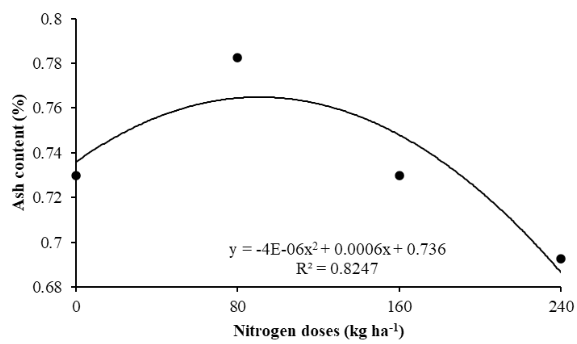

Figure 2 - Ash content of green corn grains fertigated with nitrogen rates during the summer growing season in the municipality of Canindé de São Francisco, Sergipe, Brazil.

Recent studies have shown that increasing N rates results in greater accumulation of macro- and micronutrients in the grains, leading to significant increases in ash content (Guo *et al.*, 2020; Rawal *et al.*, 2022). Singh *et al.* (2024) reported increases in iron, manganese, and zinc concentrations in response to higher N supply, while Rawal *et al.* (2022) observed increases in N, P, and K under combined nitrogen and potassium fertilization. Guo *et al.* (2020) further highlighted that optimized N application can enhance the concentrations of iron, magnesium, and manganese, although effects on potassium and phosphorus may vary according to genotype and growing environment. Thus, N plays an indirect but relevant role in the mineral composition of corn grains, with ash content serving as a sensitive indicator of this nutritional dynamic.

The mean grain pH was 6.85 and did not vary significantly as a function of N rates (Table 2). Values close to neutrality are characteristic of green corn and reflect the typical physiological state of the grains at this stage. Similar results were reported by Jiang *et al*. (2025) and Zhang *et al*. (2022), who observed pH stability between 6.5 and 7.0 regardless of nitrogen management. This consistency indicates that pH is a variable with low sensitivity to fertilization, being more strongly affected by genetic and environmental factors than by N supply. Therefore, pH stands out as a reliable parameter for assessing grain quality and biochemical integrity.

Titratable acidity showed high variability among replications (CV = 25.22%) and was not significantly influenced by N rates (Table 2), with a mean value of 2.17%. This instability is typical of volatile compounds and organic acids accumulated in the grains during the filling period, reflecting the metabolic dynamics of green corn. Recent studies indicate that acidity is more strongly influenced by genetic factors, environmental conditions, and harvest stage than by nutritional management, showing wide variability and lack of significant response to N fertilization (Correndo *et al*., 2021; Jiang *et al*., 2025). Thus, acidity remains an unstable parameter with low responsiveness to nitrogen fertilization, being more dependent on cultivar and harvest timing.

Texture, an essential sensory attribute of green corn, showed a mean value of 9.45 N and was not significantly affected by N rates (Table 2). Recent findings corroborate this trend, demonstrating that physical and sensory characteristics such as grain texture and firmness are weakly responsive to nitrogen management and are mainly determined by genotype and physiological maturity stage (Correndo *et al*., 2021; Avşar *et al*., 2025). Meta-analyses and field studies have shown that although N may alter protein, oil, and starch contents, its effects on sensory attributes such as texture are generally insignificant, remaining stable under different fertilization regimes (Correndo *et al*., 2021; Niewęgłowski *et al*., 2024; Avşar *et al*., 2025). Therefore, the stability of this variable indicates that the adopted nitrogen management did not compromise the sensory quality of green corn, preserving desirable characteristics for fresh consumption.

Overall, only ash content showed a significant response to nitrogen fertigation, while the other variables remained stable. Thus, under the edaphoclimatic conditions of the semi-arid region of Sergipe, N rates did not promote expressive changes in the evaluated physicochemical properties. The results corroborate recent findings demonstrating a stronger influence of nitrogen fertilization on mineral nutrient accumulation than on chemical or sensory quality parameters (Liu *et al*., 2022; Djalovic *et al*., 2024; Jiang *et al*., 2025). Several studies indicate that increasing N rates leads to significant increases in yield and in the accumulation of nutrients such as N, P, and K in the grains (Lin *et al*., 2022; Djalovic *et al*., 2024), whereas effects on texture, starch, and oil content are less pronounced. Therefore, nitrogen plays a determining role in the nutritional value of corn but has a limited impact on the physicochemical and sensory characteristics of the grains (Correndo *et al*., 2021; Lin *et al*., 2022; Djalovic *et al*., 2024; Jiang *et al*., 2025).

CONCLUSIONS

Nitrogen fertigation differently influenced the physicochemical attributes of green corn cultivated in the municipality of Canindé de São Francisco, Sergipe, Brazil. Among the evaluated variables, only ash content showed a significant difference among nitrogen rates, indicating a positive effect of N on grain mineral composition up to the rate of 75 kg ha^{-1}. The other parameters—moisture, pH, acidity, and texture—remained stable, demonstrating low sensitivity to increasing N supply.

The results indicate that nitrogen primarily affects the mineral content of the grains without altering the evaluated physicochemical characteristics. As the study did not include yield or sensory analyses, the conclusions are limited to postharvest physicochemical variables.

Further studies are recommended that integrate different nitrogen sources and split applications, combined with productivity and quality parameters, in order to establish more efficient and sustainable fertigation strategies for green corn cultivation in the Brazilian semi-arid region.

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