



Chemical melioration of saline soils and its residual effect on the quality and quantity of nutrients in corn grain

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ABSTRACT

Background: Soil salinization reduces the availability of micronutrients, which are essential for producing functional foods such as corn. This makes it increasingly difficult to grow food in saline soils that meet the required nutritional standards for human health. Therefore, improving soil quality through the adoption of proper farming practices is vital to ensure the continued production of functional foods and their associated health benefits.

Objective: The research was conducted from 2021 to 2024 in the Mrgashat community of the Metsamor region, Armavir marz, RA, under field conditions. The desalination and dealkalization processes and their impact on germination, growth, yield, qualitative characteristics, chemical composition, and functionality of the "Turbo" corn subtype were studied under varying flushing water standards.

Methods: The study focused on improving saline-alkaline soils through chemical melioration with sulfuric acid, using different amounts of flushing water (25%, 50%, and 100% of the calculated norm). The effects of these treatments on the soil and the qualitative properties and chemical composition of corn were assessed.

Results:

1. With the full sulfuric acid dose (7.1 kg) and 25% flushing water (9.6 m³), a decrease in soil chemical indicators was observed. Still, the corn seeds did not germinate, suggesting an insufficient combination of ameliorant and

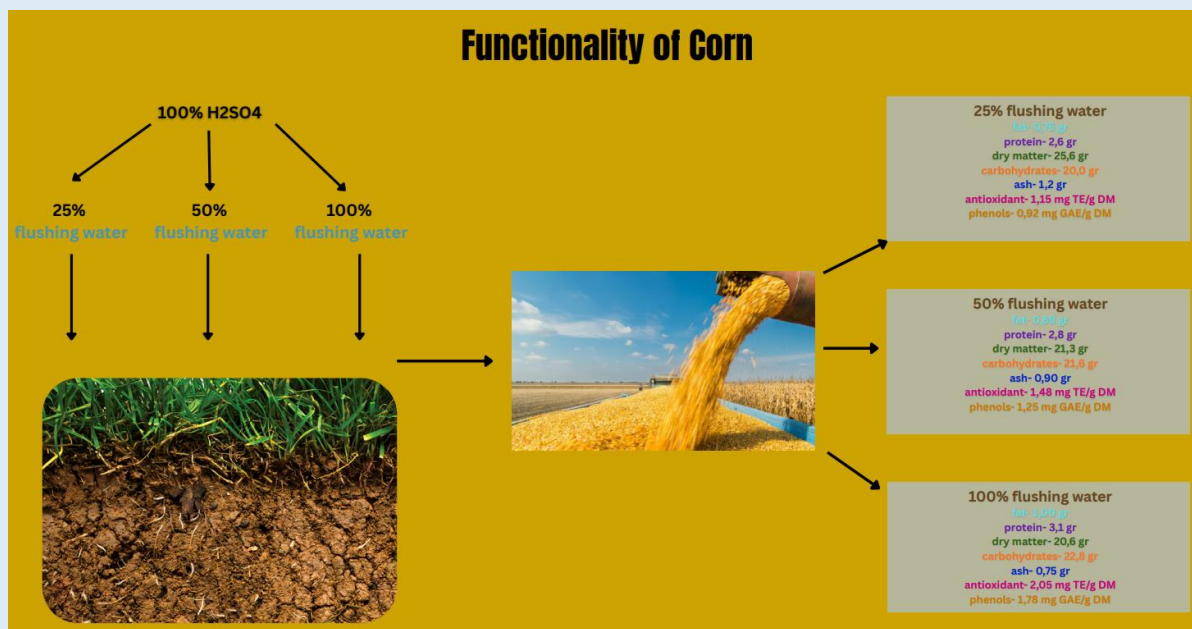
water for effective desalination. These data can serve as a basis for assessing the extent of flushing water's effect on desalination efficiency.

- When 50% flushing water (19.2 m³) was used, topsoil amelioration occurred, but significant salt accumulation remained in the deeper soil layers. Partial seed germination indicated that this amount of flushing water was not enough for complete salt removal.
- Using 100% flushing water (38.3 m³) with the full sulfuric acid dose (7.1 kg) resulted in complete desalination and alkalinization. A marked increase in calcium (Ca) in the adsorption complex was observed, enhancing plant growth and yield. In the first year of sowing, the yield reached 29.0 qt/ha, indicating that a higher flushing water dose significantly improved soil conditions and increased yield.

Novelty: This research is the first in the RA to examine the effects of different flushing water amounts on the efficiency of saline-alkaline soil amelioration and on corn growth, germination, yield, and functionality. The study emphasizes that proper selection of flushing water volume is crucial for effective salt removal, and that the combination of the ameliorant and water should be optimized to maximize desalination efficiency and high-functioning food production.

Conclusion: The research demonstrates that varying amounts of flushing water significantly influence the efficiency of soil desalination and alkalinization. The use of 100% flushing water ensures complete desalination, improves soil chemical composition, and increases both corn yield and quality. These findings provide a basis for selecting optimal amelioration practices to improve saline-alkaline soils and enhance functional food production.

Keywords: Soil salinization, desalination, dealkalization, flushing water, melioration, sulfuric acid, corn, functional food.



Graphical abstract: The effect of different quantities of chemical ameliorant and flushing water (25, 50, 100%) on the nutritional properties of the Turbo variety of maize.

INTRODUCTION

Soil salinization is a global issue, with nearly 1.4 billion hectares (over 10%) of the world's land already affected, and another billion hectares at risk due to climate change [1-3], population growth, and unsustainable human activities [4]. Salinization significantly impacts soil quality, health, vegetation growth, and crop yields [5]. Soil salinization-alkalinization poses serious threats to sustainable agriculture, food security [6-7], agricultural productivity [8–10], environmental health, and socio-economic well-being [11], leading to land degradation and the loss of essential ecosystem services, thereby challenging the ability to feed the growing global population [12–14].

Reclaiming saline-alkaline soils is essential for preserving land resources, maintaining soil health [15], and ensuring sustainable agriculture and food security. Various soil amendments are used for this purpose: gypsum [16–18], gypsum with organic fertilizers [19–21], vinasse [22], electromelioration [23], sulfuric acid with gypsum [24-25], sulfuric acid alone [26], hydrochloric acid [27], and other natural minerals or industrial byproducts.

Corn (*Zea mays* L.), a member of the Poaceae family, is an annual cereal crop. "Zea" originates from the Ancient Greek meaning "support of life," while "mays" is Latin for "life-giving." Corn is considered a functional food [28] and ranks second in cultivation area after wheat, 197 million ha vs. 216 million ha [29-30]. Due to its adaptability and high productivity, corn is often called the "queen of cereals." It is a raw material for over 3000

types of products. As a fodder crop, it is highly valued [31]; both grain and vegetative mass are used in food, industry [32], and energy sectors [33-34].

Thanks to its rich chemical composition, corn possesses functional properties [35], containing starch [36-37], protein [38-39], fat, fiber, ash [40-41], sodium, calcium, manganese, potassium, iron [42], phosphorus, magnesium, carbohydrates, carotenoids [43–45], minerals, vitamins, and antioxidants [46]. Consuming corn and other whole grains reduces the risk of chronic diseases such as cardiovascular diseases, type 2 diabetes, obesity, and some cancers, and improves digestive health [47]. Protein- and carbohydrate-rich foods are vital for health-conscious consumers, helping to reduce disease risks and support individuals with chronic and viral illnesses [48-49].

Corn is sensitive to salt stress [50]. High salt concentrations reduce corn growth and yield [51] and plant biomass [52]. Thus, reclaiming salinized and alkalized lands is essential to return them to productive use. Soil reclamation supports the production of healthy, functional food [53], benefits public health through its protective properties [54] and contributes to food security while slowing land degradation.

Improving saline-alkaline soils is a key strategy to expand arable land and cultivate valuable crops. Increasing crop production efficiency in such soils must also involve monitoring the quality of agricultural products and ensuring reliable data on toxic substances. The Ararat Plain is a major agricultural region, and soil improvement in this area is vital for addressing food

security challenges. Our research focuses on addressing these critical issues.

MATERIALS AND METHODS

The research was conducted from 2021 to 2024 in the Mrgashat community, Metsamor region, Armavir Marz, Republic of Armenia. Located at 850 m above sea level in the Ararat Plain, the area has a dry continental climate. Annual precipitation is 200–300 mm, distributed as follows: spring – 43%, autumn – 20%, winter – 20%, summer – 17%. Evaporation exceeds precipitation by 4–5 times, reaching 1100–1200 mm, which promotes soil salinization and alkalization [55]. The study was carried out under field and laboratory conditions. For field research, microplots (1.5 × 1.5 m = 2.25 m²) were used. The experiment included four variants, each with three replications.

1. Control
2. Sulfuric acid 16.0kg + flushing water 9.6m³ (25%)
3. Sulfuric acid 16.0kg + flushing water 19.2 m³ (50%)
4. Sulfuric acid 16.0kg + flushing water 38.3m³ (100%)

For laboratory research purposes, soil samples were collected from the experimental plot at a depth of 1m (0-25, 25-50, 50-75, 75-100cm) before the experiment was established. In the taken soil samples, the soil solution reaction (pH) was determined using an electrode meter by immersing it in a saturated solution (1:5 soil:water) [56], electrical conductivity (EC) by the conductometric method – HI 8733, soluble salt content, dry matter in

grain according to E. V. Arinushkina [57], Antioxidant activity determination of method: DPPH radical neutralization experiment (Brand-Williams et al., 1995) and total phenolic compounds determination of method: Folin–Ciocalteu (Singleton & Rossi, 1965), the composition of exchangeable cations in the soil adsorption complex: calcium and magnesium according to A. N. Baghramyan [60], sodium and potassium according to H. T. Ananyan and K. G. Ghukasyan [61], carbonates according to S. A. Kudrin [62], proteins, fats, carbohydrates using BKN-110 f Fully Automatic Kjeldahl Nitrogen Analyzer, ash by calculation of difference in a muffle furnace, calculation of yield amount according to B.A. Dospekhov [63].

The research results show that the soil solution reaction in all layers of the studied area is strongly alkaline, reaching 9.7 in the 0-100 cm layer, EC-8.4mS/cm, the content of soluble salts is high in all soil layers, amounting to 1.083% in the one-meter soil layer. Soda is also present (Table 1).

Thus, the studied area is a typical saline-alkaline area, and it is impossible to cultivate crops without melioration works.

The full required amount of ameliorant (16.0kg) and sulfuric acid were applied, along with 25, 50, and 100% of the water used for washing purposes.

Water with a mineralization degree of 0.996g/l was used for washing. After completion of the washing work, soil samples were collected from all variants, and the averaged data from three replications of the laboratory studies are presented in Table 1.

Table 1. Chemical composition of the water extract of the studied area in the control variant and in the variants with the full dose of ameliorant and different doses of flushing water

Options:	Layer of soil, cm	pH	EC, mS/cm	Total salts, %	Soluble ions, meq 100g of soil						
					CO ₃ ²⁻	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻	Ca ²⁺	Mg ²⁺	Na ⁺ + K ⁺
Salt-alkali (control)	0-25	9.6	8.8	1.104	1.84	4.64	6.40	4.84	0.20	0.24	15.44
	25-50	9.7	8.0	1.050	1.67	4.48	6.32	4.35	0.25	0.24	14.66
	50-75	9.7	8.1	1.075	1.77	4.67	6.18	4.57	0.25	0.16	15.01
	75-100	9.8	8.6	1.101	1.84	4.72	6.32	4.78	0.20	0.24	15.38
	0-100	9.7	8,37	1.083	1.78	4.63	6.30	4.64	0.23	0.22	15.12
H ₂ SO ₄ 16.0 kg + 25% flushing water	0-25	8,1	8,8	1,588	-	0,67	6,94	16,49	2,50	3,52	18,10
	25-50	8,0	8,7	1,550	-	0,72	6,88	15,94	2,45	3,44	17,65
	50-75	8,1	8,8	1,578	-	0,64	6,77	16,53	2,60	3,44	17,90
	75-100	8,1	8,6	1,631	-	0,67	7,05	17,04	2,60	3,68	18,48
	0-100	8,1	8,7	1,587	-	0,67	6,91	16,50	2,53	3,52	18,03
H ₂ SO ₄ 16.0 kg + 50% flushing water	0-25	8,0	7,8	0,878	-	0,84	3,86	8,76	2,90	2,88	7,68
	25-50	7,9	7,8	0,866	-	0,72	3,75	8,81	2,85	2,80	7,63
	50-75	7,8	8,0	0,904	-	0,75	3,72	9,35	3,00	2,88	7,94
	75-100	7,9	8,1	1,052	-	0,80	3,98	11,22	4,00	3,04	8,96
	0-100	7,9	7,9	0,925	-	0,78	3,83	9,53	3,19	2,90	8,05
H ₂ SO ₄ 16.0 kg + 100% flushing water	0-25	7,8	4,1	0,295	-	0,64	0,25	3,44	2,85	0,40	1,08
	25-50	7,7	4,0	0,307	-	0,64	0,28	3,47	2,65	0,40	1,34
	50-75	7,7	4,0	0,316	-	0,67	0,31	3,58	2,50	0,32	1,74
	75-100	7,7	4,0	0,335	-	0,72	0,31	3,81	2,40	0,40	2,04
	0-100	7,7	4,0	0,313	-	0,67	0,28	3,58	2,60	0,38	1,55

In the 25% flushing water variant, CO_3^{2-} is absent in all soil layers. Total HCO_3^- decreased compared to the control, reaching 0.67 meq in the 1-meter layer. Water-soluble Ca increased, but soluble salt content remains high, 1.587% in the 0–100 cm layer—making crop cultivation impractical. Additional water and continued leaching are necessary.

In the 50% flushing water variant, soda CO_3^{2-} is also absent. HCO_3^- decreased to 0.78 meq in the 1-meter layer. Water-soluble Ca increased, yet soluble salts remain high, 0.925% in the 1-meter layer. Increasing the amount of flushing water is needed to lower salt levels further and improve conditions for crop growth.

In the 100% flushing water variant, CO_3^{2-} is absent, and HCO_3^- dropped to 0.67 meq. Water-soluble Ca increased, and soluble salts decreased in all layers. In the 0–100 cm layer, salts dropped to 0.503%, though still high at 1.587% in some layers. With continued cultivation, salt content is expected to decline further as Ca^{2+} levels in the soil increase.

Overall, sulfuric acid neutralizes soil soda, reducing alkalinity and lowering pH in all treated variants compared to the control.

The exchangeable cation composition of the soil adsorption complex was also analyzed before and after amelioration. The data are shown in Figure 1.

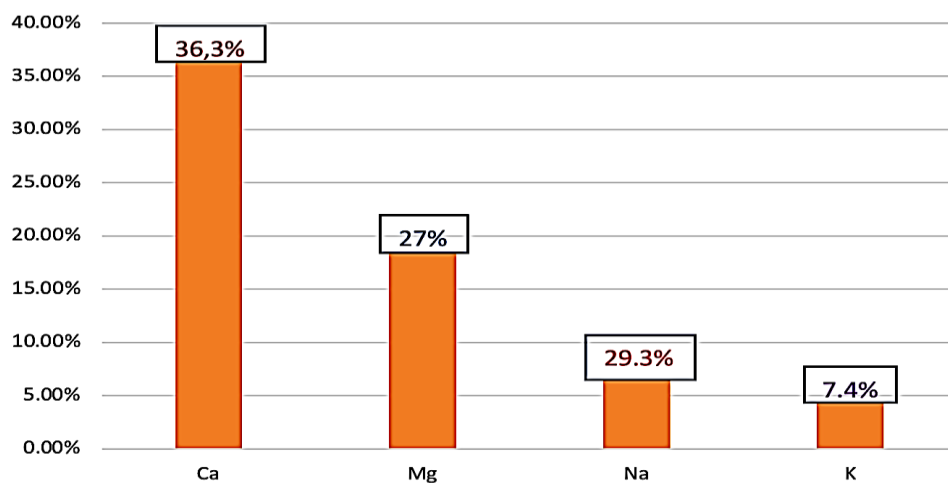


Figure 1: Composition of exchangeable cations of saline-alkaline soil

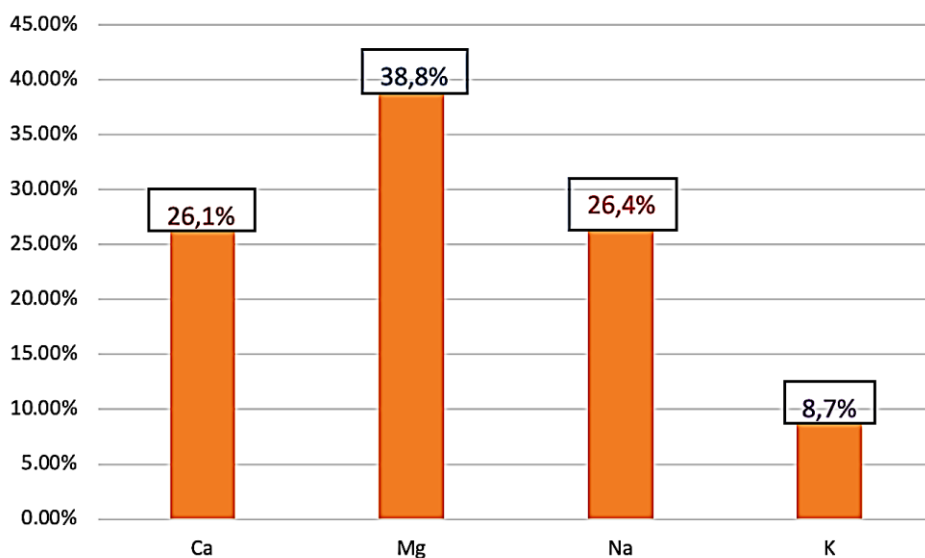


Figure 2: Change in the composition of exchangeable with 25% flushing water application

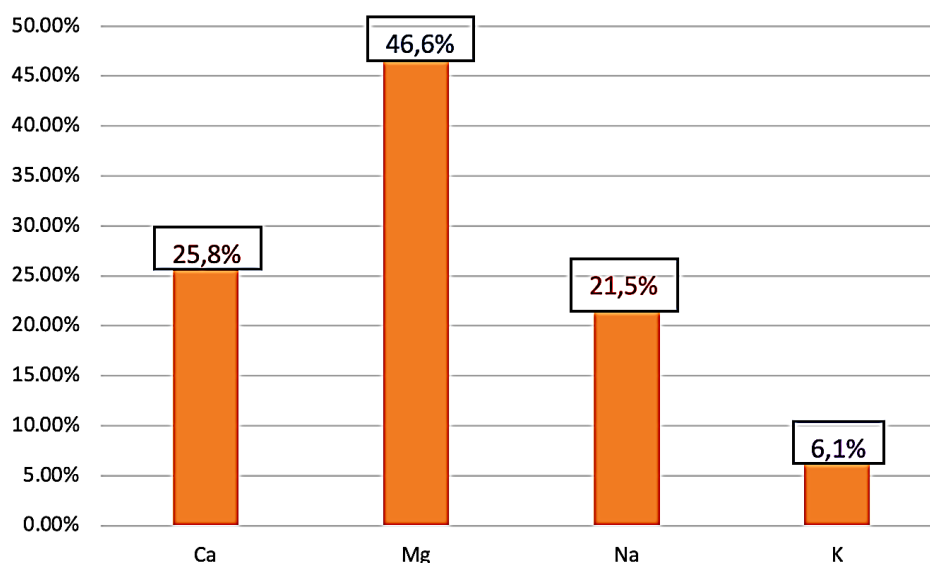


Figure 3: Change in the composition of exchangeable with 50% flushing water application

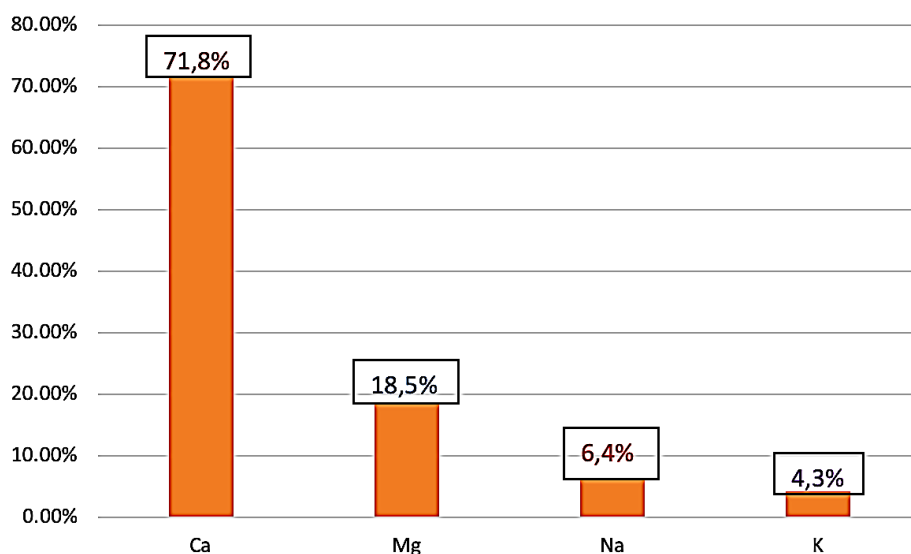


Figure 4. Change in the composition of exchangeable cations with 100% flushing water application

Changes in the composition of exchangeable cations in the soil adsorbing complex under the application of the full rate of ameliorant (100%) and different amounts of flushing water (25%, 50%, 100%): The ratio of exchangeable cations in the soil adsorption complex of the studied area before and after melioration was also studied. The research data are presented in Figure 1.

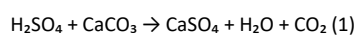
In the composition of exchangeable cations in the soil adsorption complex of saline-alkaline soil, the

amount of sodium in the one-meter (0-100cm) layer of soil is 29.30% (Fig. 1). After the completion of meliorative works, a decrease in adsorbed sodium indicators is observed in all variants compared to the control. However, according to the research data, the best variant is the application of the full sulfuric acid norm and the entire flushing water volume. In this variant, all indicators of the soil adsorption complex are within the normal range: Ca > 60%, Mg < 30%, Na < 15%, K < 5% (Fig. 4).

Table 2. The number of carbonates in the studied areas before and after melioration.

Options:	Layer of soil, cm	CaCO ₃ %		MgCO ₃ %	
		Before melioration	After melioration	Before melioration	After melioration
H ₂ SO ₄ 16.0 kg + 25% flushing water	0-25	11.80	11.50	5.00	4.00
	25-50	11.70	11.20	4.00	3.70
	50-75	11.70	11.10	4.80	4.20
	75-100	11.30	11.70	4.80	4.40
	0-100	11.60	11.40	4.70	4.10
H ₂ SO ₄ 16.0 kg + 50% flushing water	0-25	11.80	11.40	5.00	4.60
	25-50	11.70	11.50	4.00	3.80
	50-75	11.70	11.50	4.80	4.60
	75-100	11.30	11.20	4.80	4.70
	0-100	11.60	11.40	4.70	4.40
H ₂ SO ₄ 16.0 kg + 100% flushing water	0-25	11.80	10.50	5.00	4.40
	25-50	11.70	11.10	4.00	3.80
	50-75	11.70	11.10	4.80	4.60
	75-100	11.30	11.10	4.80	4.70
	0-100	11.60	11.00	4.70	4.40

Before melioration, CaCO₃ dominated among soil carbonates (up to 11.60% in the 1 m layer), with MgCO₃ at 4.70%. Under sulfuric acid treatment, carbonates decompose most actively in the 0–25 cm layer, forming calcium and magnesium sulfates:



These sulfates neutralize alkalinity, while released CO₂, dissolving in flushing water, enhances solubility and accelerates melioration. Calcium ions replace exchangeable sodium, which is leached out, leading to soil desalination and dealkalization. The “Turbo” hybrid corn (yellow, ~1.9 m tall, 18–20 grain rows per cob) was sown in all micro-plots for fresh use and canning. Table 4 data show that yield under saline-alkaline conditions was strongly affected by the full (100%) application of sulfuric acid and flushing water. The three-year average yield ranged from 5.8 to 24.7 q/ha, with the 100% treatment giving the highest yield—17.1 and 18.9 q/ha above the 25% (control) and 50% variants, respectively. The application of varying amounts of flushing water during soil desalination significantly alters the chemical composition of corn grains, thereby affecting their functional food value. Increasing the flushing water dose led to: Higher protein content (2.6–3.1%), enhancing the amino acid profile that serves as precursors for bioactive

compounds such as enzymes and antioxidant peptides, supporting immune defense, muscle tissue repair, and cellular metabolism. Increased fat content (0.75–1.00%), which plays a key role in cardiovascular health, cell membrane structure, and hormonal balance. Elevated carbohydrate content (20.0–22.8%), promoting gut microbiota balance, blood glucose regulation, and providing a prebiotic effect, a key indicator of functional food quality. Reduced ash content (1.2–0.75%), indicating lower accumulation of mineral salts, which improves the organoleptic properties and bioavailability of minerals. Despite a slight decrease in dry matter (25.6–20.6%), the overall nutrient quality improved, reflecting intensive synthesis of bioactive compounds within the plant tissues. From a functional food perspective, the H₂SO₄ (16.0 kg) + 100% flushing water treatment produced corn grains with a chemical composition that supports a health-promoting diet, providing bioactive proteins, beneficial fats, and carbohydrates that collectively aid digestive health, energy balance, cellular repair, and immune activation. Consequently, corn cultivated under these conditions can be classified as a high-functional-value product, suitable for producing functional foods, such as nutrient-enriched flours, protein supplements, and dietary blends.

Table 3. The effect of flushing water norms on the grain yield and qualitative indicators of nutrients of "Turbo" corn variety.

Options	Grain yield by years, q/ha			Average: yield, q/ha	Yield addition		Three-year average					Antioxidants activity (mgTE/gDM)	Phenols (mgGAE/g DM)
	2022	2023	2024		q/h	%	Dry matter	Proteins	Fats	Ash	Carbohydrates		
Salt-alkali (checker)	-	-	-	-	-	-	-	-	-	-	-	0,85±0,04	0,65±0,03
H ₂ SO ₄ 16.0 kg + 25% flushing water	5,4	7,1	4,9	5,8±0,21	-	-	25,6	2,6	0,75	1,2	20,0	1,15±0,05	0,92±0,04
H ₂ SO ₄ 16.0 kg + 50% flushing water	7,6	8,1	7,0	7,6±0,19	1,8	31,0	21,3	2,8	0,89	0,90	21,6	1,480,07	1,25±0,05
H ₂ SO ₄ 16.0 kg + 100% flushing water	23,6	24,8	25,7	24,7±0,34	18,9	325,8	20,6	3,1	1,00	0,75	22,8	2,05±0,09	1,78±0,06
LSD _{0,05}				0,32								0,11	0,09
LSD _{0,01}				0,51								0,17	0,14
CV(%)				4,8								5,2	6,0

Antioxidants (mg TE/g DM) content increases with leaching and decreasing soil salinity, as plant oxidative stress decreases. Phenolic compounds (mg GAE/g DM) are generally reduced under severe salinity conditions and increased under favorable growing conditions. The full ameliorant application (0–100 cm layer) with higher flushing water rates improved corn grain quality. Increasing water content reduced dry matter and ash but increased protein, fat, and carbohydrates, enhancing the functional value of the food.

Scientific Innovation: This study presents an innovative soil reclamation technique that integrates the full calculated sulfuric acid (H_2SO_4) dose (16.0 kg/ha) with graduated flushing water rates (25%, 50%, and 100%). The approach was tested in saline–alkaline soils where “Turbo” corn was cultivated over three consecutive years (2022–2024). The method achieved a dual improvement effect:

1. Desalinization and dealkalization of the 0–100 cm soil layer, leading to significant reductions in electrical conductivity and soil pH;

2. Nutrient redistribution and structural enhancement of the reclaimed soil, creating favorable conditions for root growth and nutrient uptake.

The results showed that the treatment H_2SO_4 + 100 % flushing water was the most effective, producing a yield of 24.7 q/ha, which exceeded the control by 325.8 %. This comprehensive approach offers a scientifically grounded, cost-effective strategy for large-scale reclamation of saline–alkaline lands in arid and semi-arid regions.

Practical and Functional Implications: Beyond its agronomic benefits, the proposed method significantly enhanced the functional and nutritional quality of the harvested corn. Under the optimal treatment (H_2SO_4 + 100 % flushing water), grain biochemical composition improved notably:

Proteins: 3.1 %

Carbohydrates: 22.8 %

Antioxidant activity: 2.05 mg TE/g DM (↑ from 0.85)

Total phenolic content: 1.78 mg GAE/g DM (↑ from 0.65)

These results demonstrate that soil reclamation using acid-flushing technology not only restores productivity but also increases bioactive compound concentration, giving the crop functional food potential. Enhanced levels of antioxidants and phenolics contribute to free-radical scavenging, anti-inflammatory, and metabolic-regulating effects, linking soil health improvement directly with human health benefits.

Overall, this integrated reclamation model establishes a scientific-to-functional bridge, transforming degraded soils into sources of nutritionally enriched and health-promoting crops.

Abbreviations: RA: Republic of Armenia, ANAU: Armenian National Agrarian University.

Contributions: All of the authors contributed to this study and to the creation of this article.

Competing Interests: The authors declare no financial interests or conflicts of interest.

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