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RESEARCH ARTICLE

Effect of sodium metabisulfite on storage of sugar beet roots

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Abstract

Sugar beet roots are becoming a growing source of sugar production. It provides about 40% of world sugar production. In most beet-growing areas, harvest periods are short, and storage is necessary. Deterioration of sugar beet roots leads to an increase in reducing sugar percentage and polysaccharide levels causing a decrease in sucrose content this results in a decline in physical and technological characteristics. This work was carried out in Delta Sugar Company, Kafr Elsheikh governorate, Egypt during the 2022/2023 harvest season. To reduce the deterioration of sugar beet roots after harvesting and before processing. Roots were divided into seven groups.

The first one was (a control sample) and the other six groups were treated with different concentrations of sodium metabisulfite ($Na_2S_2O_5$) from 100 to 600 mg/L (wet weight) for four days in the open air.

During this work, we revealed that by adding a concentration of 500 mg/L of sodium metabisulfite we obtained high sucrose content, beet quality, sugar recovery, and pH and we revealed that by addition of 500 mg/L of sodium metabisulfite, we obtained the lowest difference between apparent sugar and true sucrose, the lowest amount of Na, K, and α-amino-N, the lowest percentage of sucrose loss and amount of raffinose content.

At 600 mg/L of sodium metabisulfite, it will cause deterioration again because it is an acidic material that leads to increased sucrose inversion again. So, this research aims to preserve the quality of beet and prevent its deterioration by using sodium metabisulfite.

Keywords: Beet roots; Technological characteristics; Storage periods, Sodium metabisulfite; Polysaccharide

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Introduction

Sugar beet ranked the second sugar crop after sugarcane in the world, providing about 40% of the world's sugar production (Eweis et al. 2006). The importance of this crop is not only to produce sugar but also to use its top in feeding animals due to the high nutritional value of the sugar beet canopy (Dawood et al. 2023). Sugar produced from cane or beet is one of the most widely processed food items. Beet and cane sugar contribute to around 60 and 40%, respectively, of the annual total world sugar production (FAO 2023). Sugar consumption has increased over the last ten years, leading to a need to increase sugar production by expanding the cultivated area and improving root yield (Galal et al. 2022a; Ahmed 2023; Abu-Ellail et al. 2024).

The sugar industry represents one of the oldest industries and strategic goods in Egypt which contributes about 2.543 million tons of both beet and cane represented by 29.9% and 61.2% of both cane sugar and beet sugar, respectively. According to the Sugar Crops Council, Ministry of Agriculture and Land Reclamation (2023), the Egyptian annual consumption of sugar beet is 3.370 million tons, so sugar's self-sufficiency is 75.5%. Until the early 1980s, sugarcane was considered the only source of sugar production in Egypt; however, in 1982 due to the increased sugar demand and water shortage, the g Egyptian government introduced sugar beet to the Egyptian Agricultural system.

During the last few years, the Egyptian government made considerable efforts to promote the cultivation of sugar beet and beet sugar production (Abofard et al. 2021; Galal et al. 2022b). Besides, the sugar beet crop has played a significant role in Egypt's crop rotation as a winter crop and can be cultivated in fertile and poor soils that are saline, alkaline, and calcareous (El-Hawary 1999).The usual composition of a sugar beetroot is 75% water, 20% soluble solids, 16% sucrose, and 4% non-sugar compounds, which are mineral salts and nitrogenous chemicals and their excess hinders the crystallization of sugar, leading to a decrease in the quality of the crop, especially sodium and potassium salts. 5% fiber, which is used in the production of fodder (El-Zayat 2021). During storage, the chemical composition of the sugar beet changes, and thus the amount of recoverable sugar declines (Majumdar et al. 2011). Sucrolytic enzymes cleave sucrose to glucose and

fructose. These hexoses mainly fuel beet respiration, but a certain amount accumulates in the cells (Berghall et al. 1996; Klotz et al. 2006). Deterioration and decline of sucrose occur due to respiration and activation of some enzymes, resulting in a decrease in the physical and technological characteristics of sugar beet roots (Pavlů et al. 2017).

Reported that prolongation of the vegetation period in spring to 13 days increased sugar beet root yield by 10.9% (Snowden 2010). While sugar yield and quality formation are a very complicated process involving a lot of factors, (Fugate and Campbell 2009; Pačuta et al. 2017).

Mentioned that sugar loss in the beet sugar industry occurred due to three different reasons. The first one is spoilage by microorganisms which use up sugar in respiration and produce enzymes that convert sucrose to invert sugar (Majumdar et al. 2011).

Meanwhile, harvesting and cleaning of sugar beet lead to root damage, which increases storage losses due to wound healing and by causing entry points for pathogens that is the main cause of beet roots deterioration. (Kleuker and Hoffmann 2020).

Sucrose may also be lost via the formation of raffinose. Due to other enzymatic processes, Additional non-sucrose compounds accumulate within the beet. Proteins and other insoluble nitrogen compositions hydrolyze into amino acids, which can lead to an increase in the concentration of amino nitrogen that increases the amount of sucrose lost to molasses (Vukov and Hangyal 1985).

The reaction of amino acids with inverted sugar causes color formation and thereby impairs white sugar quality. The production of acids from the degradation of glutamine and inverted sugar (glucose + fructose) decreases the pH, in addition to the amount of sugar lost to molasses. Raffinose, a trisaccharide composed of glucose, fructose and galactose, decreases the rate of sucrose crystallization. Due to its incorporation into the crystal structure, the sucrose crystals change their shape to a needle-like form and become difficult to separate from the mother liquor (Harvey and Dutton 1993; van der Poel et al. 1998).

All these processes will result in quality losses, which should be kept as low as possible for economical beet processing. Fortunately, it's common practice to use preservatives to prevent spoilage due to microbial or fungal growth or unintended chemical change and overcome chemical deterioration to extend the shelf life of beet after harvesting and before processing and to study the chemical change in sugar beet storage after treating with sodium metabisulfite (SMB) or sodium pyrosulfite ($Na_2S_2O_5$) (Ilie-Mihai et al. 2022).

Material and methods

Sugar beet root sampling and experiments

The experiment was carried out at the laboratories of Delta Sugar Company, Kafr El-Sheikh Governorate, Egypt, during the 2022/2023 working season. The samples of sugar beet roots (Beta vulgaris L.) of different working cultivars were taken from the research fields of Delta Sugar Company. The sugar beet samples were cultivated in northern Egypt (29- 32° 55' N).

Roots were divided into seven groups in piles (pyramids shape) the first one was zero ppm (control sample) and the other six groups were treated with different concentrations of sodium metabisulfite ($Na_2S_2O_5$) from 100 to 600 ppm (wet weight) for four days at open-air. sodium metabisulfite was prepared as liquid stock and added to piles of beetroots samples by spraying it to cover 70% of beetroots by using 1L per peak at four days of storage "equivalent to 0.7 L per ton" Each parameter had three replicates along with days of storage.

Analysis of quality traits of beet root juice

Sucrose content

Sucrose content was determined using an automatic saccharimeter (Anton par saccharometer polarimetry/Graz/Austria) on a lead acetate basis according to the procedure of Delta Sugar Company (Le Docte 1977). As follows, the grated beet was squeezed to form beet juice then 50 ml of beet juice was diluted to a measuring flask 200 ml by adding 1ml of lead acetate to precipitate non-sugar materials, the diluted beet was filtrated by filter paper then the filtrated juice was added to a saccharimeter to read the polarization. Apparent sugar is calculated using the following equation

$$\text{DP (Direct polarization)} = \frac{R \times 200 \times 26}{50 \times 100}$$

where R is the saccharimeter reading.

True sucrose

True sucrose of the beet root juice was determined by a double polarization method. Method GS4/7-1 (1994) as described in (ICUMSA 1994). As follows, Pipette directly 50 ml of filtrate of beet root juice into a 100 ml flask and add 5 ml of hydrochloric acid and 6 ml of distilled water, insert the thermometer in the flask and place the flask in a water bath at 69 □ C for 10 min.

Remove the flask from the water bath and cool rapidly under cool running water. Remove the thermometer from the flask, rinsing it carefully into the flask and water, make the volume up to 100 ml at 20 □ C, read the polarization,

True sucrose was determined using the following equation

$$\text{True sucrose} = 0.512\text{DP} - \text{IP}/0.839.$$

where IP is the inverted polarization.

Raffinose content

Raffinose content was determined according to the procedure described by (Asadi 2006).

$$\text{Raffinose} = 0.33\text{DP} + \text{IP}/1.563.$$

where DP is direct polarization, and IP is the inverted polarization

pH measuring

pH measuring by using a digital bench pH meter, model pH-526/sentix–20/AS-DIN/SIN/STH/ 650 according to the procedure of Delta Sugar Company. A small amount of beetroot juice was poured into the beaker and the pH-meter electrode was inserted into the same beaker. After inserting the cleaned and rinsed electrode into beetroot juice, the pH reading was waited for some seconds until becoming stable (Sánchez-Moreno et al. 2006).

Total soluble solids (TSS)

Total soluble solids of fresh samples were determined using a fully automatic digital refractometer; model ATR-S (04320), 0 – 95Brix, temperature compensation 15 to 40 ºC according to the procedure of Delta Sugar Company (Le Docte 1927). As follow, the prism of the refractometer was thoroughly cleaned and a drop of each beet root juice was placed on the prism and closed immediately. The percentage of total soluble solid content was read from the scale of the refractometer then recorded it.

Reducing sugar

Reducing sugar content of the beet root juice samples was determined using Ofner's volumetric methods as described in (AOAC 1990). Samples were placed in a boiling water bath so that the solution in the tubes was just below the level of the boiling water. Care was taken to ensure that no boiling water got into the tubes. The reaction time should be exactly 10 minutes. Remove the tubes from the boiling water bath and immerse them in a cold-water bath. After a few minutes, the contents of the tubes will be sufficiently cool to be titrated. Add 5 ml of 5 N acetic acid against the tube wall, close to the liquid level, to neutralize sodium carbonate in the solution. Do not shake the tubes during this step. Immediately, add an excess amount of iodine (20 ml) until the solution becomes green. Mix and pour the contents of the tube into a 125 ml Erlenmeyer flask. Rinse the tube twice with a small amount of deionized water and add the rinse water to the flask.

The solution was well-mixed until the precipitate was completely dissolved. Five drops of starch indicator were added, and immediately titrate the excess iodine with sodium thiosulfate to the endpoint (light blue color).

The volume of thiosulfate used for the blank and each sample was recorded, and reducing sugar% was calculated using the following equation:

$$\text{Reducing sugar\%} = \frac{\text{Thiosulfate used for blank (ml)} - \text{Thiosulphate used for sample (ml)} - 0.2}{\text{Weight of sample} \times 10}$$

Moisture content

The moisture content was determined by drying the sample to constant weight at 105 □ C, using the air oven drying method according to (AOAC 1990). As follows, fresh beet root (*Beta vulgaris L.*) was obtained from a farm in Kafr El-Sheikh and stored at 3-4°C for about one day for equilibration of moisture and then used for the experiments. The initial and final moisture contents of the sample were determined according to the standard oven drying method. The initial moisture content of beetroot for all samples was found to be 483.772-654.717. Experiments were performed at 100 to 150°C. The sample was cut uniformly with the help of a stainless-steel square chopper. The weight loss of samples was measured using a weighing balance after 10-minute intervals.

The drying process was stopped when the moisture content decreased to 8.48-9.369% from an initial value of 89.53 ± 0.5% The product was cooled for 15 minutes after drying and kept in desiccators. Drying tests were replicated three times at each temperature, and averages were reported (Singh et al. 2013).

Ash content

Ash content was determined using a Muffle furnace with digital PID (Proportional-integral derivative) controller, model, CWF-11/13 at 550ºC according to the method of (AOAC 1990). As follows, take 10 ml of beet juice in a beaker and insert the electrode in the same beaker the value is shown as Milie Siemens unit.

A-amino-N, sodium, and potassium

A-amino-N, sodium, and potassium were determined using Venma, Automation BV (Basic value) Analyzer IIG-16-12-99, 9716JP/Groningen/Netherlands. Temp. 18-30ºC, surrounding humidity max. 70% according to the results calculated as milli equivalents / 100 g beet (Brown and Lilleland 1946). As follow, A representative root sample of about 20 kg of roots from each plot was used for juice quality analysis by measuring sucrose%, potassium (K)%, sodium (Na)% and α-amino-N% in the root juice.

Sugar recovery (SR), sugar losses into molasses (SL), beet quality and juice purity

Sugar recovery, sugar losses into molasses, juice purity and quality of sugar beet were determined according to the procedure described by Silin and Silina (1977) and Saponova et al. (1979) using the following equations:

$$\text{Sugar recovery\% (SR)} = \text{POL} - 0.343\,(\text{K} + \text{Na}) - (0.0939\alpha\text{N}) - 0.29.$$

$$\text{Sugar losses\% (SL)} = 0.343(\text{K} + \text{Na}) + (0.0939\alpha\text{N}) + 0.29.$$

$$\text{Purity\%} = (\text{Sucrose\%}.100)/(\text{Brix\%}).$$

$$\text{Beet Quality\%} = (\text{SR}.100)/\text{pol}.$$

Where Pol is sucrose %, K is potassium, Na is sodium, and α-N is α-amino-N.

Statical analysis

All tests were carried out in triplicate and the results were presented as mean, median, range, standard deviation (SD), and coefficient of variation (CV) using Microsoft Excel 2016 (Snedecor and Cochran 1967; Jumde and Gousoddin 2015).

Results and discussion

The general quality properties of fresh roots in the sugar factory

The sugar beet (the raw material of the beet sugar factory) composition is important to both the sugar beet farmer and the factory. Sugar (sucrose) and non-sugar (non-sucrose) content determine the quality of the sugar beet where high sugar and low non-sugar content are desirable. So, it is important to evaluate the chemical and technological characteristics of beet juice to evaluate the quality of beetroots for sugar production.

The chemical composition of fresh sugar beet roots during the beet campaign (beet-processing period) is given in Table 1.

The sucrose content of sugar beet roots was 19.16% during the beet campaign as shown in Table 1. These data were comparable with those reported by many authors (Badawy 1992; Mousa 1990; El-Sharnouby et al. 1999). A low reducing sugar value of 0.086% was found in the roots at harvest as shown in Table 1.

The results were in agreement with the findings of (Ibrahim 1970; Mousa 1990; Badawy 1992; Abou-Shady 1994; Rearick et al 1999). Table 1 showed that ash content was 3.41%.

The obtained results were in agreement with those reported by (Gaber 1979). From the data shown in the same table, the total soluble solid was found 21.42%. The result was in agreement with the findings of (El-Geddawi 1988; Mousa 1990; Badawy 1992; Abou-Shady 1994; Zalat 1993; Hozayen 2002).

Table 1. Chemical composition of fresh sugar beet roots.

Compound	Percentage %
Total soluble solids (Brix)	21.42
Sucrose	19.16
Reducing sugar	0.086
Ash	3.41

The chemical composition of fresh sugar beet roots during the beet campaign (beet-processing period) is given in Table 2.

The Sugar recovery (white sucrose) of the fresh sugar beet roots was 16.08%. Similar results were recorded by (Nassar 1992; Abou-Shady 1994). They found that white sucrose ranged between 8.76% and 16.19% (Al-Barbari et al. 2014) Table 2 showed that Sugar losses in wastes of sugar beet roots were 3.25%. Generally, the percentage of sucrose loss in wastes was within the range of 2.88% and 3.68% as reported by (Abou-Shady 1994) (Salami and Saadat 2013).

The purity of fresh sugar beetroot juice at harvest was 89.00% as shown in Table 2. These results were in good agreement with what was reported by (Zalat 1993; Hozayen 2002; Abou El-Magd et al. 2004). They found that purity of juice ranged between 81.14% and 93.74% (El-Geddawy and Abd El-Rahman 2019). Table 2 showed the quality of sugar beet roots at harvest was 83.85%. similar results were recorded by (Abou-Shady 1994; Hozayen 2002; Ferweez et al. 2006). They reported that the quality of sugar beet roots at harvest was recorded between 77.63% and 84.00%. The pH value of beet juice of healthy sugar beet roots at harvest was 6.30. These data were comparable with those reported by (Hozayen 2002). They found that the pH value of the cell juice of healthy plants ranged between 6.2 and 6.5. Sugar beet has to synthesize organic acids (Oxalic acid, Citric acid, and Malic acid).

Table 2. Technological characteristics of fresh sugar beet roots.

Compound	Percentage%
Sugar recovery	16.08
Sugar losses	3.25
Purity	89.02
Quality	83.85
pH	6.30

Effect of sodium metabisulfite on the chemical characteristics of sugar beet roots

The Effect of sodium metabisulfite on sucrose content (dry weight) in this experiment was studied, according to Table 3. They showed that sucrose content is decreased during storage due to increasing inversion of sucrose from 81.35% to 46.97%. Beetroots that were treated with different concentrations of sodium metabisulfite led to an increase in the sucrose content due to a decrease in the inversion of sucrose but not stopping. At 500 mg/L of sodium metabisulfite showed a high sucrose content of 71.78% comparable to other concentrations.

This result was in agreement with (Abou-Shady 1994) as shown in Figure 1. According to (McCready and Goodwin 1966). They showed that sugar was lost during storage as a result of three different things the first is the spoilage by microorganisms which use sugar by respiration and produce enzymes that convert sucrose into inverted sugar (Barna et al. 2017). Second is the direct respiration by stored roots which change sugar into, H_2O and energy, and the third source of sugar loss is through the biochemical transformation of sucrose into inverted sugar (Hozayen 2002). So, during the storage period, the apparent sugar was highly increased from 14.79 to 19.26% and true sucrose decreased from 17.1 to 15.98 due to an increase in the inversion of sucrose that led to an increase in apparent sucrose and a decrease in the true sucrose after the addition of sodium metabisulfite the apparent sugar was slightly increased and true sugar was slightly decreased. At 500 mg/L of sodium metabisulfite, there was less difference between apparent sugar and true sucrose comparable to other concentrations as shown in Figure 1. At 600 mg/L of sodium metabisulfite sucrose content was decreased again to 71% and the difference between apparent sugar and true sucrose was increased again to 0.93 because it is an acidic substance and adding an excess of it led to starting deterioration again and increased inversion of sucrose.

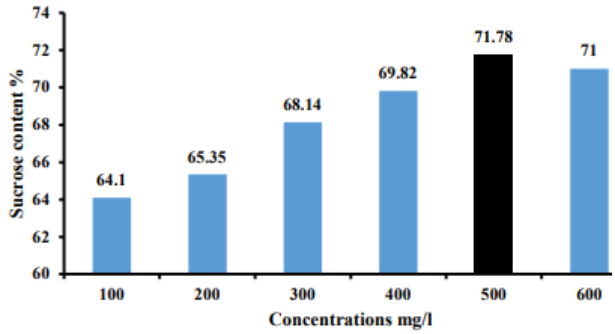

Figure 1. Effect of sodium metabisulfite different concentrations on sucrose content (dry weight) at four days of storage.

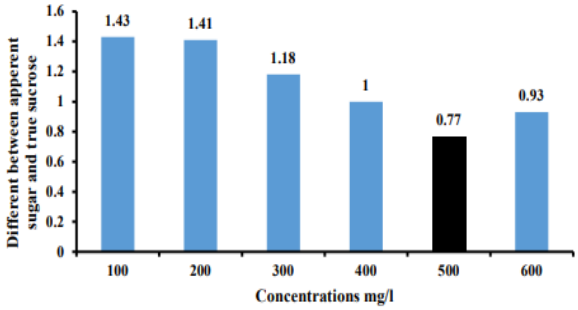

Figure 2. Effect of sodium metabisulfite different concentrations on sucrose inversion at four days of storage.

The Effect of sodium metabisulfite on raffinose content was studied.

The raffinose content of the beet is so strongly dextrorotary resulting from bio- chemical transformation of sucrose during storage that consists of three monosaccharides glucose, galactose, and fructose (O-α-d-galactopyranosyl-(1→6)-O-α-d-glucopyranosyl-(1↔2)-O-α-d-fructofuranoside) (Martin et al. 2001; Wyse and Dexter 1971). Raffinose increased at the end of the campaign due to an increase in the storage period which led to an increase in inversion of sucrose and the apparent sugar that led to an increase in the raffinose content, at zero mg/L beginning of the storage control sample raffinose was 0.25% at the end of storage raffinose increased to 0.70% that increases the sugar loss in molasses. In addition, different concentrations of sodium metabisulfite in the raffinose were slightly increased.

At 500 mg/L of sodium metabisulfite had the lowest increase of raffinose content from 0.25% on the first day to 0.45% on the last day due to decrease the ability of inversion of sucrose into inverted sugar according to Table 3 and Figure 3.

At 600 mg/L of metabisulfite, raffinose content was increased again to 0.39 %because it is an acidic substance and causes deterioration again leading to the formation of monosaccharides that combine to form raffinose

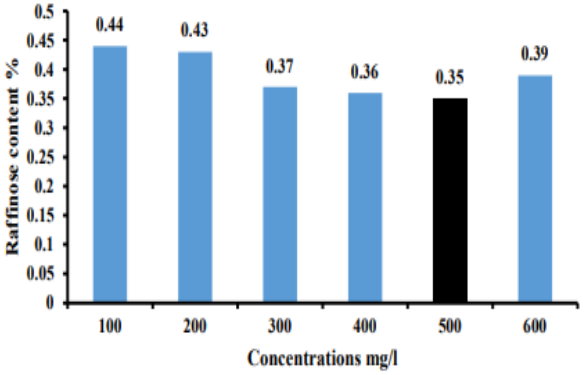

Figure 3. Effect of sodium metabisulfite different concentrations on raffinose content at four days of storage.

The Effect of sodium metabisulfite on pH was studied. The pH of sugar beet juice was decreased during storage as a result of the degradation of sucrose by enzymes into inverted sugar (glucose and fructose), which decomposed into organic acids (lactic acid) and colorant compounds causing a decrease in pH which led to an increase the rate of inversion. At the beginning of the storage control sample pH of beet juice was 6.25 and at the end of storage pH decreased to 4.90 as shown in Table 3 due to the inversion of sucrose to glucose and fructose that decomposes to acids (Terefe et al. 2010). In addition, different concentrations of sodium metabisulfite slightly decreased the beet root juice pH. At 500 mg/L sodium metabisulfite had the lowest decrease in pH becoming 5.30 at the end of storage due to the decrease in the ability of inversion of sucrose to inverted sugar according to Figure 4. At 600 mg/L of sodium, metabisulfite pH was decreased again to 5.68 because it is an acidic substance, and adding excess metabisulfite causes deterioration again and inversion of sucrose.

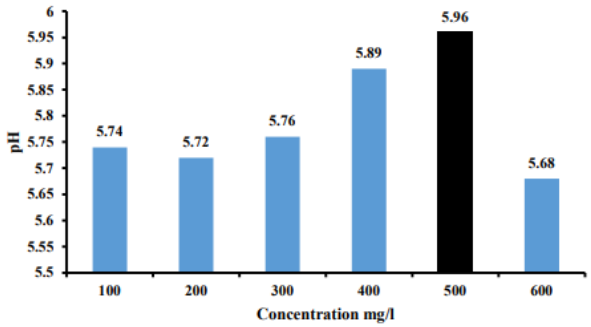

Figure 4. Effect of sodium metabisulfite different concentrations on pH at four days of storage.

Table 3. Effect of sodium metabisulfite on the chemical characteristics of sugar beet roots.

Concentration (mg/L)	Storage periods (days)	Sucrose Content (dry weight)	Apparent sugar	True sugar	Difference	Raffinose	moisture	pH
	0	81.35	17.49	17.1	0.39	0.25	78.5	6.25
	1	72.16	17.68	17.1	0.58	0.37	75.5	5.94
Zero mg/L	2	59.01	17.73	16.9	0.83	0.52	70	5.71
	3	55.58	18.9	16.02	2.88	0.58	66	5.1
	4	46.97	19.26	15.98	3.28	0.7	59	4.9
Mean		63.01	18.21	16.62	1.59	0.48	69.80	5.58
Median		59.01	17.73	16.90	0.83	0.52	70.00	5.71
Max		81.35	19.26	17.10	3.28	0.70	78.50	6.25
Min		46.97	17.49	15.98	0.39	0.25	59.00	4.90
Range		34.38	1.77	1.12	2.89	0.45	19.50	1.35
Standard deviation		12.24	0.72	0.51	1.23	0.16	6.92	0.51
C.V(%)		19	4	3	77	33	10	9
	0	81.35	17.49	17.1	0.39	0.25	78.5	6.25
	1	70.5	16.92	16.8	0.12	0.42	76	6.02
100 ppm	2	60.63	17.28	16.6	0.68	0.48	71.5	5.88
	3	57.76	18.44	16.2	2.24	0.5	68	5.3
	4	50	19.5	15.8	3.7	0.55	61	5.25
Mean		64.05	17.93	16.50	1.43	0.44	71.00	5.74
Median		60.63	17.49	16.60	0.68	0.48	71.50	5.88
Max		81.35	19.50	17.10	3.70	0.55	78.50	6.25
Min		50.00	16.92	15.80	0.12	0.25	61.00	5.25
Range		31.35	2.58	1.30	3.58	0.30	17.50	1.00
Standard deviation		10.86	0.93	0.46	1.35	0.10	6.17	0.40
C.V(%)		17	5	3	95	24	9	7
	0	81.35	17.49	17.1	0.39	0.25	78.5	6.25
	1	71.14	16.72	16.6	0.12	0.38	76.5	6.15
200 mg/L	2	64.07	17.62	16.2	1.42	0.48	72.5	6.1
	3	57.42	17.8	16.1	1.7	0.5	69	5.15
	4	52.81	19.54	16.08	3.46	0.56	63	4.99
Mean		65.36	17.83	16.42	1.42	0.43	71.90	5.73
Median		64.07	17.62	16.20	1.42	0.48	72.50	6.10
Max		81.35	19.54	17.10	3.46	0.56	78.50	6.25
Min		52.81	16.72	16.08	0.12	0.25	63.00	4.99
Range		28.54	2.82	1.02	3.34	0.31	15.50	1.26
Standard deviation		10.11	0.93	0.39	1.18	0.11	5.53	0.54
C.V(%)		15	5	2	83	25	8	9

Continue Table 3.

Concentration (mg/L)	Storage periods (days)	Sucrose Content (dry weight)	Apparent sugar	True sugar	Difference	Raffinose	Moisture	pH
	0	81.35	17.49	17.1	0.39	0.25	78.5	6.25
	1	76.35	17.56	17.01	0.55	0.29	77	6
300 mg/L	2	68.05	17.76	16.5	1.26	0.36	73.9	5.61
	3	61.58	17.86	16.35	1.51	0.39	71	5.65
	4	53.39	18.42	16.2	2.22	0.58	65.5	5.3
Mean		68.14	17.82	16.63	1.19	0.37	73.18	5.76
Median		68.05	17.76	16.50	1.26	0.36	73.90	5.65
Max		81.35	18.42	17.10	2.22	0.58	78.50	6.25
Min		53.39	17.49	16.20	0.39	0.25	65.50	5.30
Range		27.96	0.93	0.90	1.83	0.33	13.00	0.95
Standard deviation		10.03	0.33	0.36	0.67	0.11	4.63	0.33
C.V(%)		15	2	2	56	31	6	6
	0	81.35	17.49	17.1	0.39	0.25	78.5	6.25
	1	76.44	17.2	17	0.2	0.3	77.5	6
400 mg/L	2	71	17.82	16.88	0.94	0.35	74.9	5.9
	3	65.3	17.96	16.4	1.56	0.41	72.5	5.71
	4	55.03	18.16	16.25	1.91	0.5	67	5.6
Mean		69.82	17.73	16.73	1.00	0.36	74.08	5.89
Median		71.00	17.82	16.88	0.94	0.35	74.90	5.90
Max		81.35	18.16	17.10	1.91	0.50	78.50	6.25
Min		55.03	17.20	16.25	0.20	0.25	67.00	5.60
Range		26.32	0.96	0.85	1.71	0.25	11.50	0.65
Standard deviation		9.14	0.34	0.34	0.66	0.09	4.11	0.23
C.V(%)		13	2	2	66	24	6	4
	0	81.35	17.49	17.1	0.39	0.25	78.5	6.25
	1	78.81	17.34	16.93	0.41	0.32	78	6.1
500 mg/L	2	70.24	17.56	16.72	0.84	0.35	75	6.09
	3	68.5	17.8	16.88	0.92	0.4	74	6.08
	4	60	18.17	16.85	1.32	0.45	70	5.3
Mean		71.78	17.67	16.90	0.78	0.35	75.10	5.96
Median		70.24	17.56	16.88	0.84	0.35	75.00	6.09
Max		81.35	18.17	17.10	1.32	0.45	78.50	6.25
Min		60.00	17.34	16.72	0.39	0.25	70.00	5.30
Range		21.35	0.83	0.38	0.93	0.20	8.50	0.95
Standard deviation		7.65	0.29	0.12	0.35	0.07	3.07	0.34
C.V(%)		11	2	1	45	19	4	6

Effect of sodium metabisulfite on quality parameters of sugar beet roots

The results are shown in Table 4. The results showed that sugar recovery depends on some factors such as apparent sugar and Na, k, and α-amino-N so sugar recovery has a positive correlation with apparent sugar and a negative correlation with Na, k, and α-amino-N, so at zero mg/L, the sugar recovery was very high equal 14.89% because sugar beet roots. In this case, is fresh so it has the highest amount of sucrose but after the beet roots were stored and deteriorated that led to increase the sucrose inversion, so the sugar recovery was decreased. sodium metabisulfite was added in different concentrations to decrease the deterioration and slightly decrease the sugar recovery so 500 mg/L (the critical concentration) showed the best percentage of sugar recovery 14.79% comparable to other concentrations as shown in Figure 5. (Rorabaugh and Norman 1956). At 600 mg/L of sodium metabisulfite sugar recovery was decreased again due to sucrose inversion was increased once again that result from the acidity of substance that caused deterioration again.

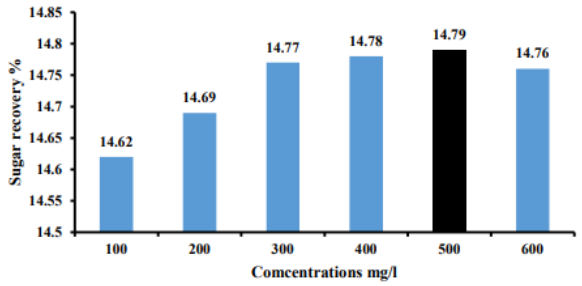

Figure 5. Effect of sodium metabisulfite different concentrations on sugar recovery% at four days of storage.

The results showed in Table 4 that sucrose loss increased during storage as well as after the addition of chemical treatment but a loss in the sample without the addition of $Na_2S_2O_5$ (zero mg/L) from (2.73% to 4.08%) was higher than the loss after addition chemical treatment this due to increase the water loss during respiration of beet (Mohamed et al. 2023). The action of invertase which sucrose transformed into inverted sugar. According to the sucrose loss equation Na, K, and α-amino-N are increased during storage so sucrose loss increased but after addition, different concentrations of sodium metabisulfite showed a slight increase in sucrose loss, especially at 500 mg/L concentration showed the lowest increase in sucrose loss from 2.73% to 3.38% and lowest percentage of sucrose loss 2.87% than other concentrations due to decrease less amount of Na, K, and α-amino-N as shown in Figure 6 (Abou-Shady 1994).

At 600 mg/L of sodium metabisulfite, the sucrose inversion starts to increase again, and Na, K, and α-amino-N are increased also because it is an acidic substance that cause the formation of microorganisms that leads to deterioration again and moisture is decreased again so sucrose loss is increased once again.

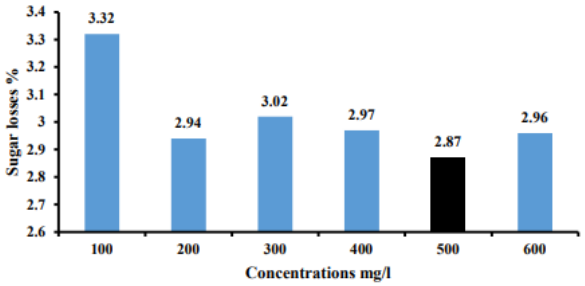

Figure 6. Effect of sodium metabisulfite different concentrations on sugar loss at four days of storage.

During the storage period the quality of sugar beet roots in control samples was decreased higher than in samples that were treated with sodium metabisulfite (treated samples) as shown in Table 4 because, during the storage period in control samples, the inversion of sucrose was increased leading to the formation of inverted sugar, raffinose a dextran that led to increase the apparent sugar that resulted in decreasing the quality another reason is due to decreasing the amount of water content during respiration of roots that led to increasing the amount of Na, K, and α-amino-N that effect on sugar recovery and led to decrease the beet quality so at the beginning of storage periods in control sample the quality of sugar beet roots was 84.33% at the end of storage was 78.76%. But after the addition of chemical treatments ($Na_2S_2O_5$) the inversion of sucrose was decreased so apparent sugar was slightly increased while Na, K, and α-amino-N were slightly increased also, so the sugar recovery didn't affect thus the sugar beet root quality was slightly decreased, at 500 ppm showed the lowest decrease in quality of sugar beet roots from 84.33% to 81.16% and showed highest beet quality comparable to other concentrations 83.66% as shown in Figure 7. These findings are in agreement with those reported by (Carter 1986). Who found that high sucrose concentrations and root quality were generally associated with low N uptake low Na concentration, high K: Na ratio, and low water concentration in the roots. At 600 mg/L of sodium metabisulfite the quality of beetroots was decreased again due to an increase in sucrose inversion was increased again which caused the apparent sugar (pol) to increase and increased amount of Na, K, and α-amino-N.

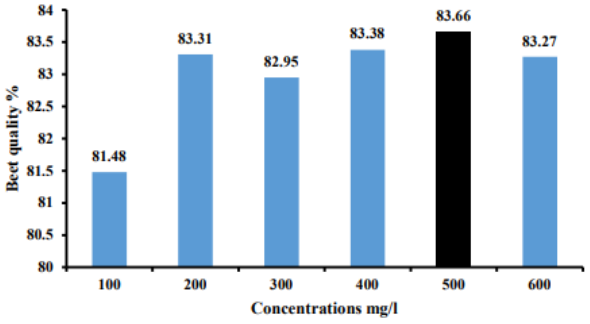

Figure 7. Effect of sodium metabisulfite different concentrations on sugar beet roots quality at four days of storage.

In general, the amount of sodium content was increased during the storage periods due to the high loss of moisture. The effect of chemical treatment on storage samples resulted in the amount of sodium being slightly increased during the storage period, and these results were acceptable with (El-Geddawi 1988).

That they found an increase in sodium content prolonging the storage of sugar beet roots. As shown in Table 4 the amount of sodium content in control samples (zero ppm) increased from 3.49 ml equivalent/100 g beet on the first storage day to 4.12 ml equivalent/100 g beet on the last storage day.

After adding sodium metabisulfite to different concentrations the amount of sodium content was slightly increased because the loss of moisture content in treated samples was less than the loss of moisture content in control samples and because sodium metabisulfite contained sodium in their chemical composition.

At 500 mg/L of sodium metabisulfite showed less amount of sodium content 3.02% than other concentrations as shown in Figure 8.

At 600 mg/L of $Na_2S_2O_5$, the amount of sodium was increased again to because the moisture content decreased again and the addition excess of substance increased sodium content.

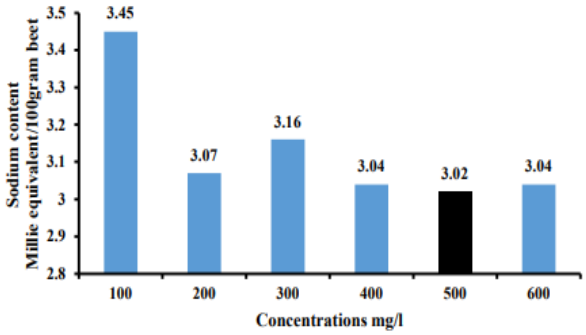

Figure 8. Effect of sodium metabisulfite different concentrations on sodium content at four days of storage.

It was clear that an increase in Na and potassium content led to an increase in the impurities, this chemical had adverse effects on the percentage of sucrose and purity (Payne et al. 1964). According to (El-Geddawi 1988).

The amount of potassium content was increased prolonging the storage periods from 3.47 ml equivalent/100 g beet to 5.99 ml equivalent/100 g beet due to the high loss of moisture as shown in Table 4.

The Effect of chemical treatment by different concentrations on storage samples resulted in the amount of potassium is slightly increased during storage period because the amount of moisture slightly decreased.

At 500 mg/L of sodium metabisulfite showed the less increase of potassium from 3.47 ml equivalent/100 g beet to 5.01 ml equivalent/100 g beet and less content of potassium 4.14 ml equivalent/100 g beet comparable to other concentrations as shown in Figure 9.

At 600 mg/L of $Na_2S_2O_5$ potassium content was increased again beet due to a decrease the moisture content.

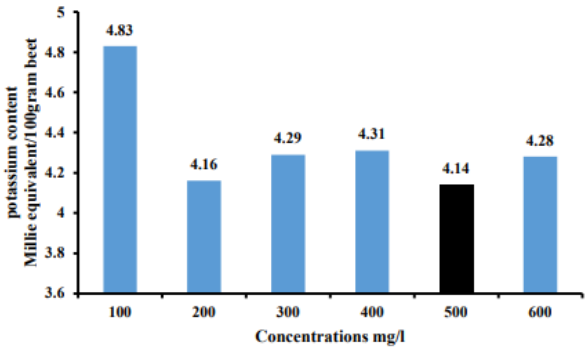

Figure 9. Effect of sodium metabisulfite different concentrations on potassium content at four days of storage

As shown in Table 4 the amount of α-amino-N was increased during the storage period from 0.62 ml equivalent/100 g beet in the first storage period to 3.50 ml equivalent/100 g in the last storage period.

This result was an agreement with (El-Geddawi 1988). Who found an increase of α-amino-N prolonging the storage period was a result of loss of moisture during storage and hydrolysis of protein, α-amino-N decreased the production of refined sugar and had a bad effect on juice purification and formed milliard products (Ram 1978). By the addition of different concentrations of sodium metabisulfite, the amount of α-amino-N was slightly increased because the loss of moisture was decreased.

At 500 mg/L especially showed the lowest increase of α-amino-N from 0.62 ml equivalent/100 g beet to 2.10 ml equivalent/100 g and less content of α-amino-N 1.4 ml equivalent/100 g comparable to other concentrations as shown in Figure 10.

At 600 mg/L of $Na_2S_2O_5$, the amount of α-amino-N was increased again due to the increase in the beet deterioration that caused sucrose inversion and decreased moisture.

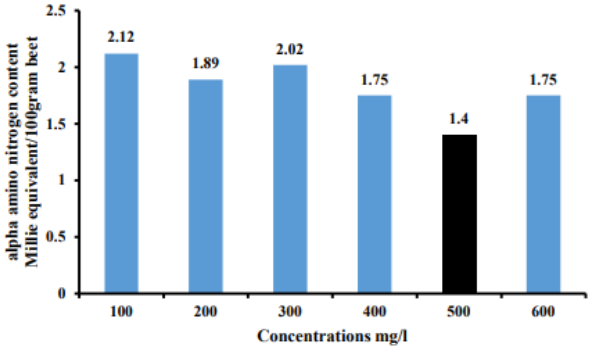

Figure 10. Effect of sodium metabisulfite different concentrations on α-amino-N content at four days of storage.

Table 4. Effect of sodium metabisulfite on the Technological characteristics of sugar beet roots.

Concentration (mg/L)	Storage periods (days)	Na	k	α-amino	Sugar recovery %	Sugar losses %	Quality %
	0	3.49	3.47	0.62	14.75	2.73	84.33
	1	2.75	4.75	1.50	14.67	3.00	82.97
Zero mg/L	2	3.64	4.97	1.90	14.30	3.42	80.65
	3	3.72	4.36	2.80	15.57	3.32	82.38
	4	4.12	5.99	3.50	15.17	4.08	78.76
Mean		3.54	4.71	2.06	14.89	3.31	81.82
Median		3.64	4.75	1.90	14.75	3.32	82.38
Max		4.12	5.99	3.50	15.57	4.08	84.33
Min		2.75	3.47	0.62	14.30	2.73	78.76
Range		1.37	2.52	2.88	1.27	1.35	5.57
Standard deviation		0.45	0.82	1.00	0.44	0.46	1.93
C.V(%)		13	17	49	3	14	2
	0	3.49	3.47	0.62	14.75	2.73	84.33
	1	2.39	4	1.5	14.29	2.62	84.45
100 mg/L	2	3.57	5.03	2.44	13.81	3.46	79.91
	3	3.85	5.72	2.85	14.69	3.84	79.66
	4	3.95	5.94	3.2	15.55	3.98	79.05
Mean		3.45	4.83	2.12	14.62	3.33	81.48
Median		3.57	5.03	2.44	14.69	3.46	79.91
Max		3.95	5.94	3.20	15.55	3.98	84.45
Min		2.39	3.47	0.62	13.81	2.62	79.05
Range		1.56	2.47	2.58	1.74	1.36	5.40
Standard deviation		0.56	0.96	0.94	0.57	0.56	2.39
C.V(%)		16	20	44	4	17	3
	0	3.49	3.47	0.62	14.75	2.73	84.33
	1	2.53	3.7	1.44	14.15	2.56	84.62
200 mg/L	2	2.75	3.91	1.53	14.91	2.71	84.61
	3	2.85	4.27	2.7	14.81	2.98	83.2
	4	3.75	5.45	3.2	14.82	3.74	79.8
Mean		3.07	4.16	1.90	14.69	2.94	83.31
Median		2.85	3.91	1.53	14.81	2.73	84.33
Max		3.75	5.45	3.20	14.91	3.74	84.62
Min		2.53	3.47	0.62	14.15	2.56	79.80
Range		1.22	1.98	2.58	0.76	1.18	4.82
Standard deviation		0.46	0.70	0.93	0.27	0.42	1.83
C.V(%)		15	17	49	2	14	2

Continue Table 4.

Concentration (mg/L)	Storage periods (days)	Na	k	α-amino	Sugar recovery%	Sugar losses %	Quality %
	0	3.49	3.47	0.62	14.75	2.73	84.33
	1	2.29	3.71	1.65	15.05	2.5	85.7
300 mg/L	2	3.01	3.96	1.69	14.92	2.74	84
	3	3.32	4.44	2.98	14.62	3.23	81.85
	4	3.71	5.89	3.19	14.53	3.88	78.88
Mean		3.16	4.29	2.03	14.77	3.02	82.95
Median		3.32	3.96	1.69	14.75	2.74	84.00
Max		3.71	5.89	3.19	15.05	3.88	85.70
Min		2.29	3.47	0.62	14.53	2.50	78.88
Range		1.42	2.42	2.57	0.52	1.38	6.82
Standard deviation		0.49	0.86	0.95	0.19	0.49	2.38
C.V(%)		16	20	47	1	16	3
	0	3.49	3.47	0.62	14.75	2.73	84.33
	1	2.33	3.71	1.66	14.68	2.51	85.34
400 mg/L	2	2.68	3.85	1.96	15.1	2.71	84.73
	3	2.99	4.23	1.98	15.01	2.95	83.57
	4	3.72	6.29	2.57	14.34	3.98	78.96
Mean		3.04	4.31	1.76	14.78	2.98	83.39
Median		2.99	3.85	1.96	14.75	2.73	84.33
Max		3.72	6.29	2.57	15.10	3.98	85.34
Min		2.33	3.47	0.62	14.34	2.51	78.96
Range		1.39	2.82	1.95	0.76	1.47	6.38
Standard deviation		0.51	1.02	0.64	0.27	0.52	2.29
C.V(%)		17	24	36	2	18	3
	0	3.49	3.47	0.62	14.75	2.73	84.33
	1	2.38	3.74	1.2	14.83	2.5	85.52
500 mg/L	2	2.85	4.17	1.4	14.73	2.82	83.88
	3	2.98	4.32	1.7	14.85	2.95	83.42
	4	3.43	5.01	2.1	14.79	3.38	81.16
Mean		3.03	4.14	1.40	14.79	2.88	83.66
Median		2.98	4.17	1.40	14.79	2.82	83.88
Max		3.49	5.01	2.10	14.85	3.38	85.52
Min		2.38	3.47	0.62	14.73	2.50	81.16
Range		1.11	1.54	1.48	0.12	0.88	4.36
Standard deviation		0.41	0.53	0.50	0.05	0.29	1.43
C.V(%)		13	13	35	0	10	2
	0	3.49	3.47	0.62	14.75	2.73	84.33
	1	2.33	3.71	1.66	14.68	2.51	85.34
600 mg/L	2	2.68	3.72	1.96	15.15	2.66	85.01
	3	2.99	4.23	1.98	15.01	2.95	83.57
	4	3.72	6.29	2.57	14.19	3.96	78.13
Mean		3.04	4.28	1.76	14.76	2.96	83.28
Median		2.99	3.72	1.96	14.75	2.73	84.33
Max		3.72	6.29	2.57	15.15	3.96	85.34
Min		2.33	3.47	0.62	14.19	2.51	78.13
Range		1.39	2.82	1.95	0.96	1.45	7.21
Standard deviation		0.51	1.03	0.64	0.33	0.52	2.64
C.V(%)		17	24	36	2	18	3

Conclusions

From this investigation, we observed that storage of sugar beet roots in open air led to an increase in the amount of Na, K, and A-amino-N, an increase in the Raffinose content, an increase in inverted sugar, an increase in the difference between apparent sugar and true sucrose and sugar loss, and led to a reduction in sucrose content, beet root quality, sugar recovery and pH. In addition to the chemical treatment using sodium metabisulfite from 100 to 600 ppm, optimizing these previous parameters, at 500 mg/L we obtained high sucrose content, high sugar recovery, high pH, and high beet quality, and at 500 mg/L we obtained less amount of raffinose content, less difference between apparent sugar and true sucrose and less amount of Na, K, and α-amino-N content comparable to other concentrations.

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