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Levels of reducing sugars in eight Kenyan potato cultivars as influenced by stage of maturity and storage conditions

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Key words
Reducing sugars, Cultivars, harvest time, storage temperature, reconditioning

1 SUMMARY

The cultivar, harvest time and storage method affect reducing sugars content of potato, which in turn influences the processing quality of French fries. Eight Kenyan potato cultivars (Tigoni, Desiree, Dutch Robyjn, Kenya Karibu and Kenya Sifa) and three advanced clones (393385.47, 391696.96 and 393385.39) were studied to determine their suitability for the chipping industry, and to determine the effect of harvesting time and storage conditions on their processing quality. Early harvesting of tubers resulted in significantly higher ($P \leq 0.05$) levels of reducing sugars (0.33-0.45 %) than harvesting at maturity (0.15-0.37 %). No significant change ($P > 0.05$) occurred in the reducing sugar content when tubers were stored at ambient air conditions (15-19 ºC / 86-92 % RH) for up to 12 weeks. In cold storage (4 ºC / 95 % RH), tubers of all the cultivars accumulated more reducing sugars and none was suitable for chipping even after reconditioning for up to 3 weeks at ≥15 ºC. Cold stored potatoes may, however, be suitable for mashing and or general home use. The information obtained in this study will inform Kenyan farmers and processors regarding the appropriate harvesting time and storage conditions for potatoes produced for chipping.

2 INTRODUCTION

Potato is a plant of the Solanaceae family that is commonly grown for starchy tubers. It is the fourth largest crop in terms of fresh produce after rice, wheat and maize (Kabira & Lemaga, 2003; MoA, 2005). According to the National Policy on Potato Industry (MoA, 2005), potato in Kenya is important for food security and income generation, being second only to maize in terms of production and utilization.

The most important products in the Kenyan potato processing industry are potato chips (French fries), followed by crisps and frozen chips whose demand has rapidly increased as witnessed by rapid growth of fast food restaurants and snack bars in urban areas (Walingo *et al.*, 2004). The processing industry requires potatoes with well-defined tuber characteristics of suitable consumer preference and processing qualities. Important factors and considerations include the level of sugars, dry matter content, variety, stage of maturity, storage and reconditioning treatments. Sugar in

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potato tubers is important and it is directly linked to the color of the final product after frying. Among the sugars, the group of reducing sugars including fructose, glucose and sucrose that cause browning is the most important.

High reducing sugars content in the tuber causes darkening as a consequence of maillard reaction (between reducing sugars and amino acids), and are therefore undesirable. Low content of reducing sugars is preferred as they result in light colors of desirable quality. Sugar levels in a potato tuber are influenced by several factors, e.g. genotype, the environmental conditions and cultural practices during growth, and storage conditions. Physiological maturity of the tuber is also important and immature tubers have higher content of reducing sugars than fully matured tubers (van Es & Hartmans, 1987).

The genetic component, however, has the strongest influence since the reducing sugars content is a heritable trait that can be screened for in tubers (Stevenson *et al*., 1964). Accumulation of sugar during storage has also been shown to be cultivar specific.

During cold-induced sweetening of stored potatoes, starch degradation occurs primarily through the action of starch phosphorylase and eventually reducing sugars accumulate through various enzymatic reactions (Morell & Rees, 1986; Sowokinos, 1990).

The major potato variety used for processing French fries in Kenya is called Tigoni, and it was released 10 years ago by the National Potato Breeding Programme. Its major adoption followed poor performance of variety Nyayo due to susceptibility to late blight and viral diseases (Kabira, 2002). Variety Tigoni is late maturing and its late blight resistance is already breaking down (Ooko *et al*., 2006). Varieties with higher dry matter content and lower reducing sugars content are required by processors to replace or compliment the cv. Tigoni, which also greens rapidly upon harvest and has poor storability under ambient air conditions, especially when exposed to light as is the normal practice in local Kenyan markets. Many other potato varieties and advanced clones presumed to be superior in terms of resistance to late blight and viral diseases, and high in dry matter have been released by the National Potato Research Centre, and these require evaluation to determine their suitability.

The primary objective of this study was to determine the levels of reducing sugars in 8 potato cultivars including 5 Kenyan varieties and three advanced clones developed in Kenya to determine their suitability for the chipping industry; the second objective was to determine the effect of harvesting time (stage of maturity) and storage conditions on tuber processing quality.

3 MATERIALS AND METHODS

3.1 Potato growing: Five varieties (Tigoni, Desiree, Dutch Robyjn, Kenya Karibu and Kenya Sifa) and three advanced clones coded as 393385.47, 391696.96 and 393385.39 from the International Potato Center (CIP, Nairobi) were grown at the National Potato Research Center (National Potato Breeding Programme), Tigoni in the year 2007 under standard cultural conditions (Lung'aho & Kabira, 1999). The crop was dehaulmed two weeks before harvesting and allowed to cure at ambient air conditions (15-19 ^{o}C/86-92 % RH) for three weeks. The potatoes were harvested at 90 or 120 days after planting. The processing and evaluation were carried out in the food science laboratories at the Kenya Agricultural Research Station (KARI) in Tigoni (processing and sensory evaluation), the Jomo Kenyatta University of Agriculture and Technology (chemical and colour analysis) and at the College of Agriculture and Veterinary Sciences of the University of Nairobi (validation of chemical analysis results).

3.2 Determination of total reducing sugars: Reducing sugars were determined by the Luff-Schoorls method number 4 of the International Federation of Fruit Juice Producers (1985).

3.3 Frying: Potato samples (10 tubers per cultivar) were peeled before cutting into strips (12 mm x 12 mm) that were washed and dried before frying using a deep fat fryer (frifri E6 ARO S.A Neuveville Swisse-Switzerland) equipped with a thermostatically controlled electric heating coil. The strips were pre-fried at 170 ^{o}C for 2 min (par frying)

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and finish-fried afterwards at the same temperature for 5 additional minutes before evaluation.

3.4 Sensory and color evaluation of French fries: Coded samples were presented to 10 panellists who were familiar with French fries. Panel members scored for colour, texture, flavour, oiliness and overall acceptability on a 9-point hedonic scale (Larmond, 1977) ranging from 1 (extremely dislike) to 9 (extremely like). A score of 5 was the lower limit of acceptability. The evaluations were carried out between 10 am and 12.30 p.m. since sensory evaluation requires that samples are analyzed either mid morning or afternoon to avoid influence due to hunger or satisfaction (Larmond, 1977). Post frying darkening was assessed on a scale of 1 (very good) to 5 (very poor) according to French fry color chart (NIVAA, 1984).

3.5 Storage and reconditioning of tubers: After curing, ware potatoes were packed in plastic net bags approximately 18 kg in weight for storage experiments. Each of the 8 cultivars was stored under ambient air conditions (15-19 ^{o}C/86-92 % RH) for 12 weeks in a dark naturally ventilated store and in a cold store (4 ^{o}C/95 % RH) for 3 months. Reducing sugar levels were monitored at monthly intervals during storage and at weekly intervals during reconditioning of the cold-stored tubers.

3.6 Data analysis: Data were subjected to analysis of variance (ANOVA) and means separated by the Least Significant Difference test using Statistical Analysis System (SAS version 9). Pearson correlation analysis was also performed to determine linear relationships where necessary.

4 RESULTS AND DISCUSSION

4.1 Influence of stage of maturity on reducing sugar content: Tubers harvested at 120 days after planting in all varieties and clones had significantly less reducing sugars ($P \leq 0.05$) as compared to those harvested at 90 days (Fig. 1). Cultivar Dutch Robyjn and clone 391691.96 had the lowest levels of reducing sugars when harvested at 120 days. The highest sugar content was 0.48 % for clone 393385.47 and 0.37 % in clone 393385.39 at 90 and 120 days after planting, respectively. The results show that all the cultivars tested had acceptable levels of reducing sugars, since potatoes for French fry processing should have total reducing sugars < 0.5 % (Nielson & Wickel, 1967; Kabira & Lemaga, 2006).

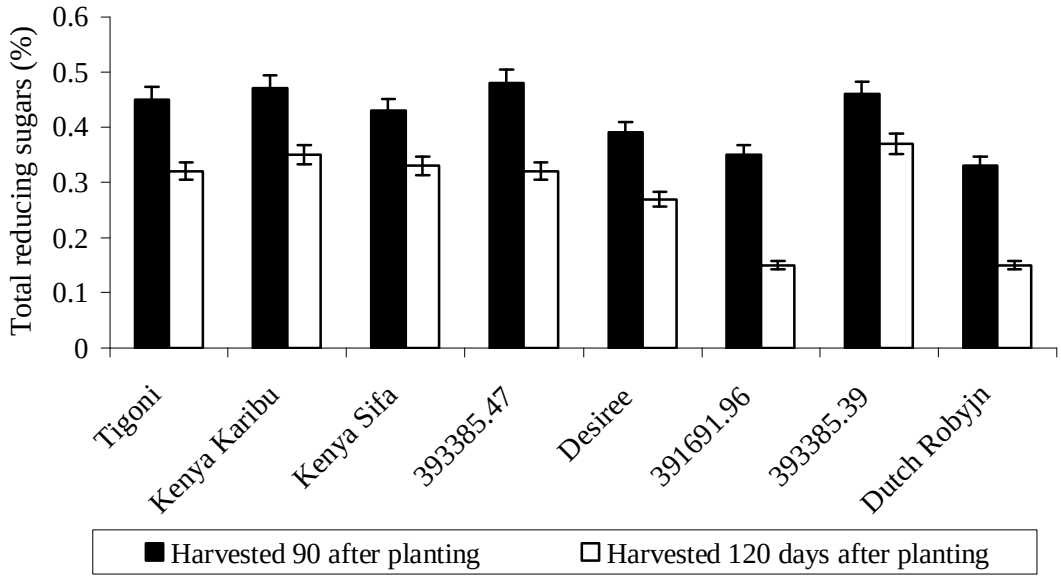

Figure 1: Reducing sugar content (%) of tubers harvested 90 and 120 days after planting. The bars indicate statistically significant differences ($P \leq 0.05$).

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Besides factors such as environmental (e.g. temperature), or cultural practices (e.g. mineral nutrition, harvesting and storage conditions), genetic component has a strong influence on reducing sugar levels in a mature tuber as well as in the rate of conversion during storage (van Es & Hartmans, 1987; Kumar *et al*., 2004). Potato cultivars have been bred specifically for French fries processing having in mind the levels of reducing sugar required. Reducing sugars in the potatoes react with amino acids in a non-enzymatic browning process known as maillard reaction. This reaction results in production of brown to dark coloration in foods depending on the amount of reducing sugars and amino acids present. High levels of reducing sugars would result in production of dark brown French fries as opposed to the required golden brown color, leading to rejection by consumers (Hamernik & Hanneman, 1998; Guar *et al*., 1999).

There was a significant ($P \leq 0.05$) correlation coefficient ($r=0.69$) between reducing sugar content and objective color scores (Table 1). Based on reducing sugar content, and as shown by the relationship between reducing sugar contents, sensory and objective color measurements, all the 8 cultivars tested in this study except clone 393385.39 could be used for chipping, according to the panelists (Table 2).

The reduction in sugar content between 90 and 120 days was due to conversion of reducing sugar to starch as tubers matured (Talburt & Smith, 1967; Kabira, 1990; Kumar *et al*., 2004). Similar gradual reduction of total reducing sugars in tubers during growth has been reported by Kabira (1983) and Boyed and Duncan (1981). It is therefore beneficial to harvest at full maturity to obtain tubers with required sugar levels.

Table 2: Pearson correlation coefficient (r) between levels of reducing sugars and NIVAA colour scores.

Parameters	Reducing sugars content	NIVAA colour scores
Reducing sugars	1.00	0.69 [a]
NIVAA colour scores	0.69[a]	1.00

[a] Significant correlation coefficient ($P \leq 0.05$). ($N=32$).

4.2 Influence of storage conditions on reducing sugar content

4.2.1 Ambient air storage condition: In all cultivars, tubers harvested 90 days after planting had no significant ($P>0.05$) difference in total reducing sugar content between freshly harvested tubers and after 12 weeks of storage at ambient air conditions (15-19 ^{o}C/86-92 % RH). This was also the case for tubers harvested 120 days after planting. This outcome suggests that the ambient air conditions did not trigger any sugar accumulation or reduction in either of the two differently harvested batches, and could therefore be appropriate for long term storage. Such results were also reported by Kabira (1983) for varieties Kerr's Pink, Desiree and Kenya Baraka.

4.2.2 Cold storage: In cold storage (4 ^{o}C), reducing sugars increased in all cultivars harvested at 90 and 120 days after planting (Figure 2 and 3). After one month of cold storage, the reducing sugar accumulation was slow but steady in all the cultivars examined. In the second and third month, there were significant ($P \leq 0.05$) differences in reducing sugar levels between all the cultivars. Rates of sugar accumulation in the 3rd month were higher than in the first month as evidenced by sharp ascent of the graphs. For all cultivars the final level of sugar accumulation was directly proportional to the initial sugar level in the tuber, as previously reported (Kumar *et al*., 2004).

At temperatures below 10 ^{o}C starch is converted to reducing sugars that then accumulate (Talburt & Smith, 1967; Hertog *et al*., 1997). Matsuura-Endo *et al.* (2004) worked on six Japanese potato cultivars and found that when stored at 4 ^{o}C, most of the cultivars had increased reducing sugars and sucrose contents.

Due to the need to prolong storage life (minimize sprout, withering and spoilage), it has been proposed that tubers can be stored at as low as 4 ^{o}C and then reconditioned at ≥15 ^{o}C prior to use (Nielsen & Wickel, 1967). However, not all varieties respond positively to reconditioning (Kumar *et al*., 2004). In this study, reconditioning for 3 weeks (maximum recommended period) following 3 months of cold-storage did not reduce total reducing sugars to desirable levels (below 0.5 %) in all the cultivars tested when harvested at 90 or 120 days after planting (Figure 4 & 5).

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Table 2: Sensory and NIVAA colour scores, and reducing sugar content of 8 potato cultivars when harvested 90 and 120 days after planting.

Cultivar	Harvest	Sensory colour score[a]	NIVAA colour scores[b]	% Reducing sugar content
393385.39	A	4.92e	2.00a	0.46a
393385.39	B	6.10b	1.75b	0.36b
393385.47	A	5.3c	2.00a	0.48a
393385.47	B	5.54c	1.75b	0.31c
391691.96	A	6.53b	1.50c	0.35cd
391691.96	B	7.30a	1.00d	0.14e
Desiree	A	7.00a	1.00d	0.39ab
Desiree	B	7.50a	1.00d	0.26d
Dutch Robyjn	A	6.8ab	1.50c	0.33c
Dutch Robyjn	B	7.30a	1.00d	0.16e
Kenya Karibu	A	6.30b	1.50c	0.47a
Kenya Karibu	B	6.31b	1.50c	0.33c
Kenya Sifa	A	5.50c	1.50c	0.43a
Kenya Sifa	B	6.53b	1.00d	0.32c
Tigoni	A	6.90ab	1.00d	0.43a
Tigoni	B	6.50b	1.00d	0.31c
CV (%)		16.36	7.33	3.65
LSD (P≤0.05)		0.63	0.15	0.02

[a]Evaluation was done on 9-point hedonic scale. A score of 5 was the acceptable lower limit.
[b]Scores of 2.5 and below are acceptable on a scale of 1 to 5.
Means followed by the same letter along each column are not significantly different.
A=90 days after harvesting, B=120 days after harvesting.

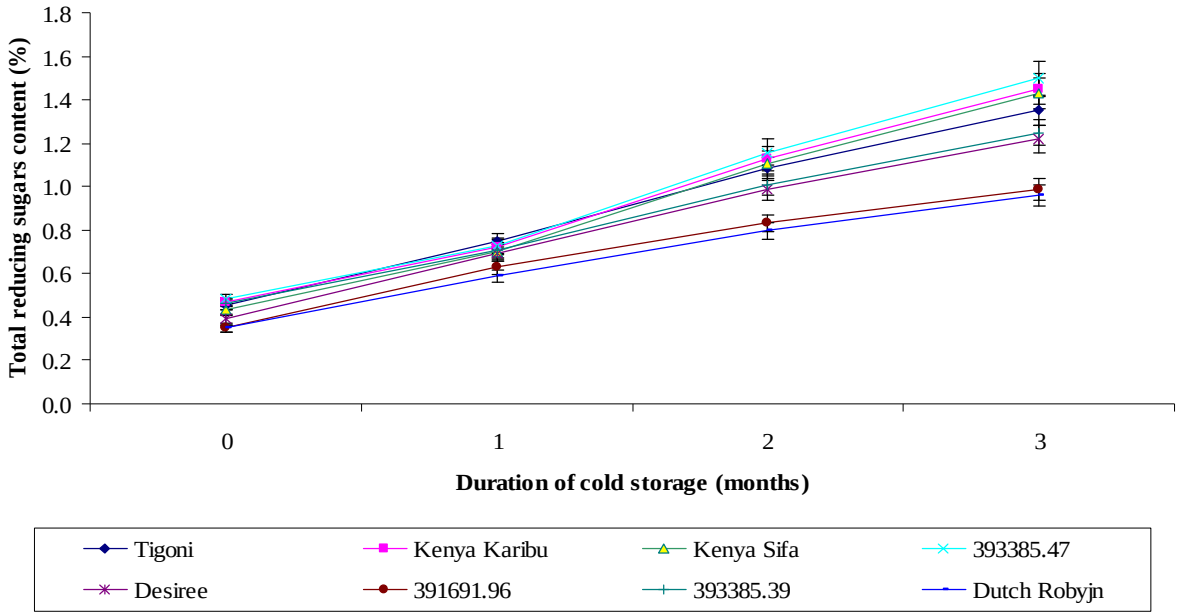

Figure 2: Variation in total reducing sugars of tubers harvested 90 days after planting and kept in cold storage at 4 °C. The bars indicate statistically significant differences (P≤0.05).

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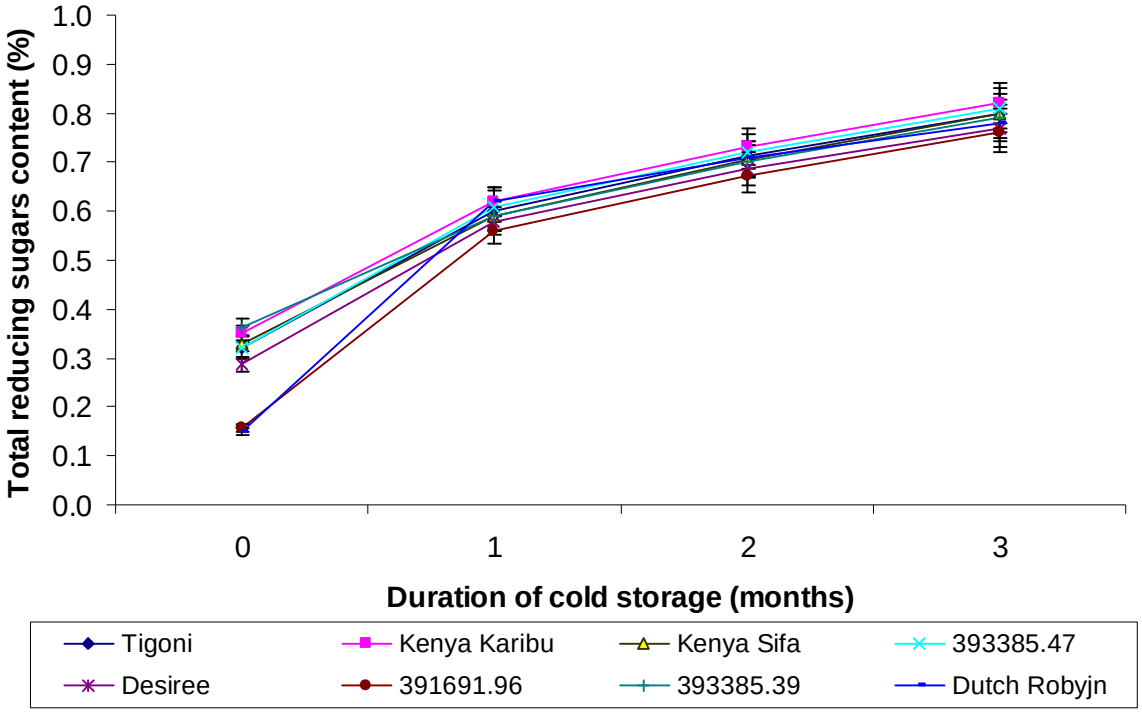

Figure 3: Variation in total reducing sugars of tubers harvested 120 days after planting and kept in cold storage at 4 °C. The bars indicate statistically significant differences (P≤0.05).

The French fries produced from cold stored potatoes from all the cultivars were dark brown and had burnt flavors that were rated as unacceptable by the taste panelists. This result shows that none of the varieties kept in cold stores and later reconditioned at air temperatures can be used for processing French fries. Research can, however, be carried out to come up with varieties that can either be chipped directly from cold storage or after reconditioning so as to reap the benefits of potato cold storage (Sowokinos, 1996). Breeding programs that can develop such cultivars should be encouraged.

4.2.3 Conclusion and recommendations: The eight cultivars evaluated in this study differed significantly (P≤0.05) in their reducing sugar levels when harvested at 90 and 120 days after planting. The levels were, however, within the acceptable range (below the 0.5 %) required for processing into French fries. Therefore all these varieties and clones are suitable for chipping provided they are harvested at maturity and stored at ambient air conditions. They may therefore be promoted to the potato processing industry for commercial use when fresh. Although they are unsuitable for chipping, cold stored potatoes of the evaluated varieties may however be suitable for mashing and or general home use.

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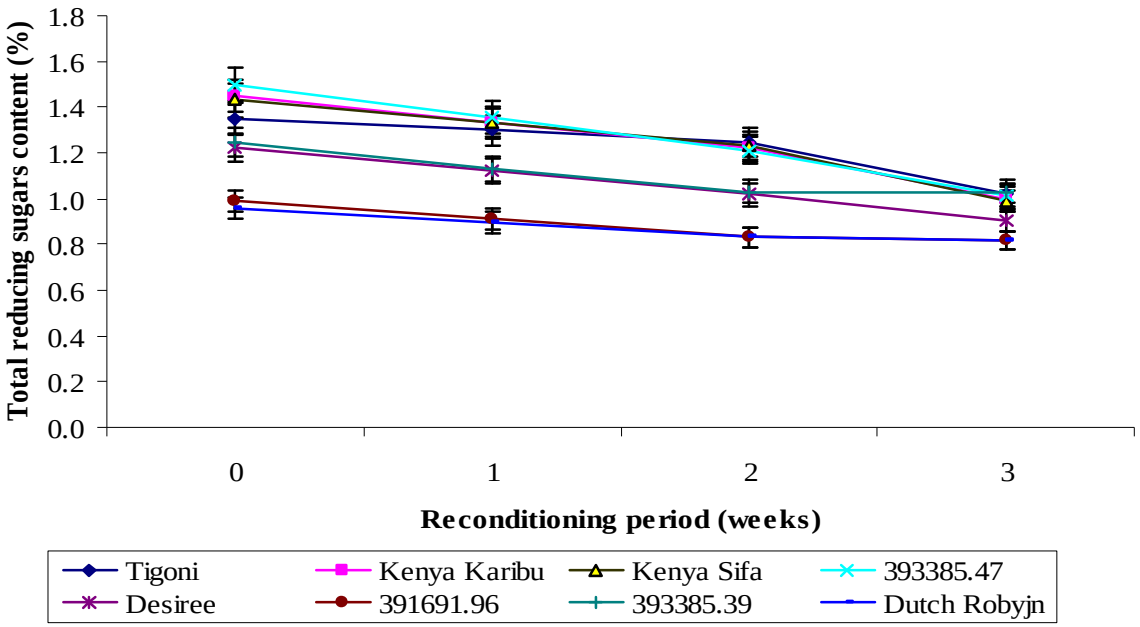

Figure 4: Effect of reconditioning period on total reducing sugars content in potato tubers harvested 90 days after planting and kept in cold storage at 4 °C for 3 months. The bars indicate statistical significant differences (P≤0.05).

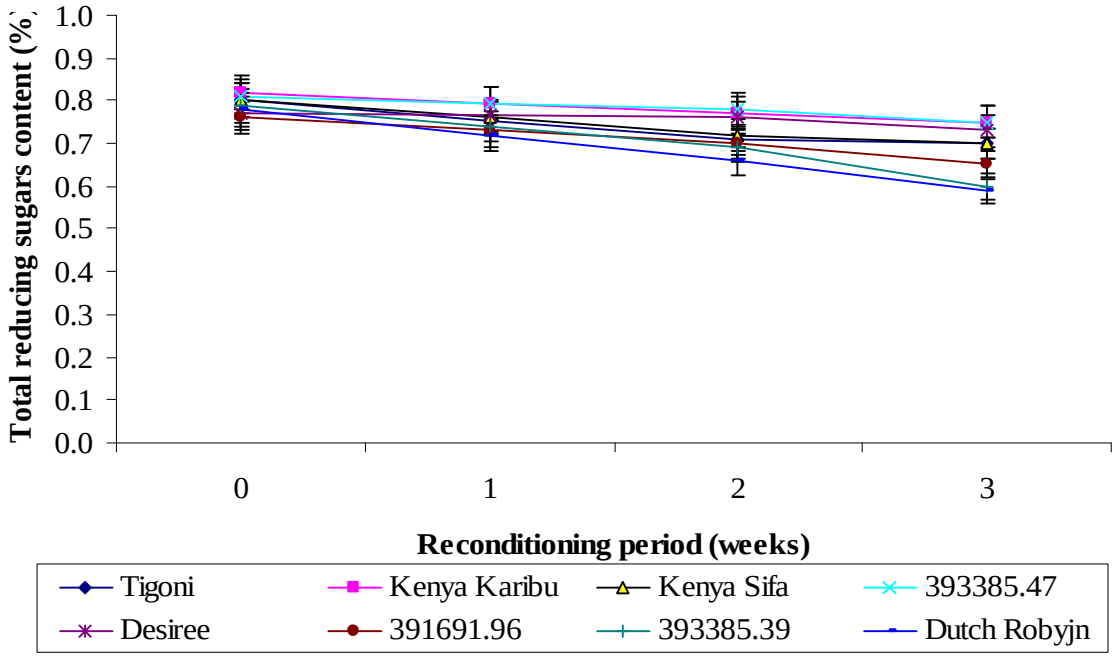

Figure 5: Effect of reconditioning period on total reducing sugars content in potato tubers harvested 120 days after planting and kept in cold storage at 4 °C for 3 months. The bars indicate statistical significant differences (P≤0.05).

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