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Full Length Research Paper

Taro corm quality in response to planting date and post-harvest storage: I. Starch content and reducing sugars

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The effect of four planting dates (October, November, December and January) and three fertilizer application rates (0, 160 and 320 kg ha^{-1} of nitrogen) on starch and reducing sugar content was investigated for three taro landraces (*Dumbe-dumbe, Mgingqeni*and*Pitshi*) from KwaZulu-Natal, South Africa, which were produced at two sites, Ukulinga and Umbumbulu. The effect of two storage temperatures (12℃ and ambient temperature: 21℃ ±3) and three packaging methods (polyethylene bags, mesh bags and open cardboard boxes) on starch and reducing sugars following storage was determined. At Ukulinga, delaying planting significantly decreased starch content, whereas at Umbumbulu starch content was significantly decreased by application of fertilizer. Reducing sugars were decreased by delayed planting when no fertilizer was applied, but increased when high N amount was applied at Ukulinga. Fertilisation had no effect on reducing sugars of *Dumbe-dumbe* but increased reducing sugars of *Mgingqeni.* For *Pitshi,* reducing sugars were increased when high N fertilizer was applied. At Umbumbulu, delaying planting generally increased reducing sugars for *Dumbe-dumbe* and *Pitshi* and decreased reducing sugars for *Mgingqeni.* Ambient temperature and mesh bag storage showed the best combination for taro cormel storage.

Key words: Landrace, nitrogen, organic fertilizer, packaging material, site, storage temperature.

INTRODUCTION

Taro [*Colocasia esculenta* (L.) Schott] commonly known as *amadumbe* in Zulu, has a high potential for alleviation of food insecurity in rural areas of KwaZulu-Natal. Recent developments indicated that taro also has a potential to compete with potato (*Solanumtuberosum*) as a processing crop to produce crisp chips. However, no research has been done on the pre- and post-harvest physiology of taro. Starch and sugar contents are important quality parameters in crisp making as texture and colour of crisps depend on them (Kita, 2002; Lisińska and Laszczyński, 1989; Pavlista, 1997). There is lack of knowledge on the effects of pre- and post-harvest practices on the carbohydrate quality of taro. It is important to understand the factors that influence the starch and sugar contents, especially reducing sugars, of taro cormels to monitor storage quality. In potatoes, higher starch content is required for processing (Mitch, 1984). Starch and sugar properties vary with potato cultivars (Lisińska and Laszczyński, 1989). Starch and sugar contents are also affected by cultivar, temperature, moisture and soil fertilization during crop production (Lisińska and Laszczyński, 1989; Wolfe et al., 1991; Feltran et al, 2004). Starch quality is influenced by environmental conditions during crop growth and storage. Potato cultivars differ in their sensitivity to storage temperature. Reducing sugar content of tubers was reported to have increased sharply during the first weeks of storage at 4℃ whereas at 10℃, reducing sugar content remained constant or increased only slightly (Cottrell et al., 1993).

Proietti et al. (2005) reported large variation in total

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soluble sugars (glucose, fructose and sucrose) between cultivars and the sowing times in potatoes. Reduced incorporation of assimilates into starch in the tubers at high temperatures and increased amount of labeled sucrose was reported by Wolfe et al. (1991). Nitrogen has a more pronounced effect than phosphorus or potassium fertilizers. High amounts of nitrogen (200 kg ha^{-1}) resulted in low starch content and high reducing sugars in potatoes due to prolonged growing season, which resulted in immature tubers at harvest (Lisińska and Leszczyński, 1989; Sowokinos, 1990). Kyriacou et al. (2009), on the contrary, reported that tuber sucrose and reducing sugar content were not affected by nitrogen fertilization when 0, 100, 200 and 300 kg ha^{-1} were applied in spring potatoes. Water deficit during growth was found to increase reducing sugars (Sowokinos, 1990; Nadler and Heuer, 1995). High nitrogen fertilization was also reported to reduce storability of potato tubers (Casa et al., 2005).

Planting taro at appropriate times, using suitable fertilization, cultivars and proper storage could enhance taro carbohydrate properties required for processing. The objective of this study was to evaluate carbohydrate changes in three taro cultivars from KwaZulu-Natal, South Africa, as affected by planting date, crop fertilization and storage temperature and packaging material.

MATERIALS AND METHODS

Taro cormels harvested from trials (Mare, 2010) that were planted at Ukulinga (29°37´S 30°16´E) and Umbumbulu (29°36´S 30°25´E) were used to assess the effect of planting date and fertilisation on reducing sugars and starch content of three landraces. The experiment was designed at each site as a split-split-plot design with four planting dates: October, 2007; November, 2007; December, 2007 and January, 2008 as main plots, three landraces (*Dumbe-dumbe*, *Mgingqeni* and *Pitshi*) as sub-plots and three organic fertilizer (Gromor Accelerator®) application rates (0, 160 N and 320 N kg ha^{-1}) as sub-sub-plots. Each planting date was replicated three times. Plot size was 4 m^2 containing 16 plants spaced 0.5 m between and within rows, respectively. Sowing was done by hand on ploughed and harrowed fields. Planting holes were opened with a hand-hoe and organic fertilizer was mixed with soil before one cormel was planted per hole. Weeds were controlled by hand-hoeing and ridging at 30, 60, 90 and 120 days after planting. Harvesting was done eight months after planting.

Cormels harvested from Ukulinga site that was planted without fertilizer in October were also used to evaluate the effect of storage temperature and packaging method on reducing sugars and starch content. The post-harvest storage experiment was arranged in a split-split plot design with temperatures (12°C and ambient temperature: 21°C ±3) as main plots, packaging (polyethylene bag, cardboard box and mesh bag) as sub-plots and landraces (*Dumbe-dumbe*, *Mgingqeni* and *Pitshi*) as sub-sub-plots. Each storage temperature was replicated three times and the cultivars were randomised within packaging within storage temperatures. Each packaging contained 13 cormels of *Dumbe-dumbe*, *Mgingqeni* and *Pitshi*, respectively. One cormel was sampled monthly for four months starting from one month after storage.

The cormels were then peeled, cut into slices and immediately frozen in liquid nitrogen, freeze-dried and milled for reducing sugars and starch determination.

Reducing sugar determination

Reducing sugars were determined at harvest and, thereafter, monthly for four months starting one month after storage according to Matsuura-Endo et al. (2006) with modifications. Peeled freeze-dried and ground cormel material (0.2 g) was homogenized for 30 s using Ultraturrax in 10 ml of 80% ethanol. The sugars in the homogenate were extracted at 80°C for 1 h and then stored overnight at 4°C. They were centrifuged at 10,000 rpm for 15 min at 4°C. The supernatant was filtered through glass wool and dried overnight in a Savant Vacuum drier. Dried samples were re-suspended in 2 ml ultrapure water and then centrifuged for 15 min. A 0.4 micron nylon syringe filters was used to filter into HPLC sample vials. The concentrations of sugars in the filtrate were then determined using HPLC (Shimadza) (Kontron Autosampler HPLC 360, 515 HPLC pump) with a Ca^{2+}- column. Reducing sugar content was calculated by adding glucose and fructose contents together.

Starch content determination

Starch content was determined as glucose equivalents resulting from enzymatic hydrolysis of the centrifugate from sugar determination using the method of Rasmussen and Henry (1990).

Statistical analysis

Analysis of variance was performed using GenStat Version 11.1 (2008). Least significant difference (LSD), at a probability level of 0.05 was used to separate means.

RESULTS

Reducing sugar content

Reducing sugar content was significantly affected by the interaction of planting date and fertilization (P = 0.001) at Ukulinga. When no fertilizer was applied, reducing sugars significantly decreased when planting was delayed by one month from October (Figure 1). Planting date had no effect on reducing sugars when 160 kg ha^{-1} of N fertilizer was applied. Delaying planting until January increased reducing sugar content of cormels when 320 kg ha^{-1} of N fertilizer was applied. There was no significant difference between fertilizer rates when planting was done in October and November. Fertilizer application of 160 kg ha^{-1} N showed higher reducing sugar content than when no fertilizer was applied but not higher than when 320 kg ha^{-1} N was applied, which was also not significantly different from when fertilizer was not applied for the December planting. The 320 kg ha^{-1} N displayed significantly higher reducing sugars than both 0 and160 kg ha^{-1} N, when planting was done in January.

At Umbumbulu, planting date significantly (P=0.018)

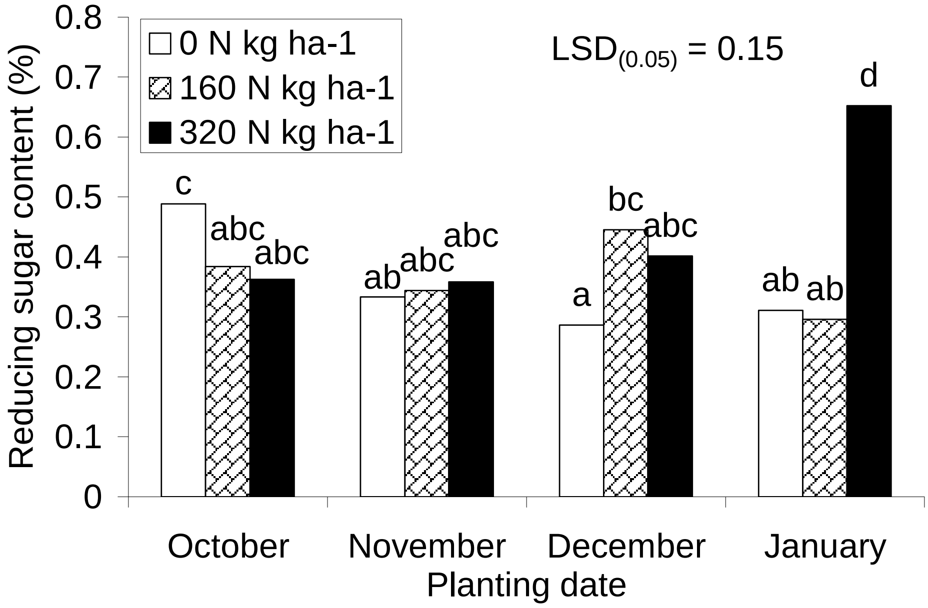

Figure 1. Reducing sugar in taro cormels planted at different planting dates averaged across cultivars at Ukulinga.

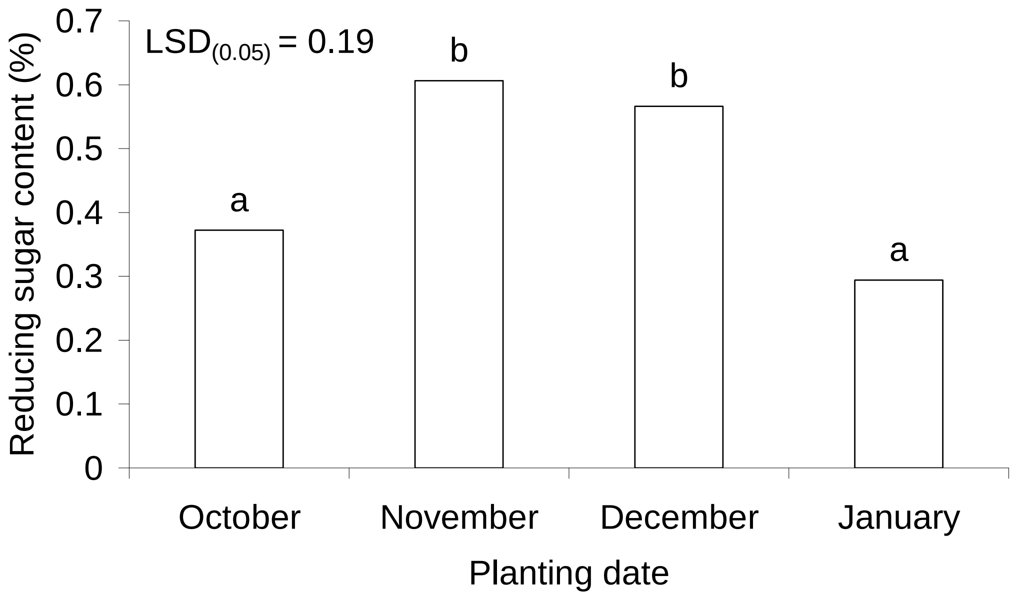

Figure 2. Reducing sugar content of taro cormels planted at different planting dates averaged across cultivar and Gromor Accelerator® application rate at Umbumbulu.

affected reducing sugar content of taro cultivars. Delaying planting by one month from October significantly increased reducing sugar content (Figure 2). Further delay in planting until January decreased reducing sugar content to a level not significantly different from that obtained with October planting.

In the storage experiment, reducing sugars were significantly (P=0.002) affected by the interaction of temperature, packaging, landrace and sampling date. Reducing sugars generally increased with time in storage. Taro cormels stored at 12°C generally showed higher reducing sugars than those stored at ambient

Table 1. Reducing sugar content of taro cultivars stored at different temperatures in different packaging materials. Means of the interaction effect within columns (LSD $_{(0.05)}$ = 0.12) followed by the same letter are not significantly different.

Temperature	Packaging	Cultivar	Months after storage			
			1	2	3	4
12℃	Polyethylene	*Dumbe-dumbe*	0.09 abc	0.09 ab	0.13 a	0.36d
		Mgingqeni	0.08 abc	0.10 abc	0.28 bc	0.34 cd
		Pitshi	0.03 a	0.10abc	0.37 c	0.39 d
	Box	*Dumbe-dumbe*	0.07 abc	0.11 abc	0.16 ab	0.65e
		Mgingqeni	0.11 abc	0.18 bc	0.41 c	0.68 e
		Pitshi	0.09 abc	0.10 abc	0.11 a	0.34 cd
	Mesh bag	*Dumbe-dumbe*	0.15 bc	0.21 c	0.31 c	0.43 d
		Mgingqeni	0.08 abc	0.10 abc	0.15 a	0.36 d
		Pitshi	0.04 ab	0.08 ab	0.12 a	0.14 ab
Ambient Temperature	Polyethylene	*Dumbe-dumbe*	0.05 abc	0.15 abc	0.15 a	0.17 ab
		Mgingqeni	0.17c	0.11 abc	0.11 a	0.13 ab
		Pitshi	0.06 abc	0.07 ab	0.12 a	0.17 ab
	Box	*Dumbe-dumbe*	0.09 abc	0.10 abc	0.18 ab	0.20 ab
		Mgingqeni	0.08 abc	0.09 ab	0.16 a	0.20 ab
		Pitshi	0.06 abc	0.09 ab	0.11 a	0.14 ab
	Mesh bag	*Dumbe-dumbe*	0.05 ab	0.07ab	0.10 a	0.23 bc
		Mgingqeni	0.04 ab	0.04 a	0.09 a	0.10 a
		Pitshi	0.10 abc	0.12 abc	0.14 a	0.16 ab

temperature, especially after 4 months after storage (Table 1). Cormels of *Dumbe-dumbe* and *Mgingqeni* packaged in cardboard boxes displayed higher reducing sugars compared with those packaged in polyethylene and mesh bags, respectively.

Starch content

Starch content was significantly (P = 0.014) affected by the interaction of planting date and landraces at Ukulinga. Starch content significantly decreased for *Dumbe-dumbe* with delay in planting from November to December, whereas for *Pitshi* the decrease was observed with delay in planting from December to January (Figure 3). Planting date had no effect on starch content of *Mgingqeni*. *Dumbe-dumbe* displayed significantly highest (P<0.05) starch content when planting was done in November. There was no significant difference between landraces when they were planted in October, December and January.

At Umbumbulu, planting date (P = 0.045) and the interaction of cultivar and fertilisation (P = 0.01) had significant effects on starch content of taro cormels. Starch content was significantly increased when planting was delayed by two months from October (Figure 4). Application of 320 kg ha^{-1}N of fertilizer decreased starch content of *Dumbe-dumbe* to the level not significantly different from that obtained with no fertilizer (Figure 5). Fertilizer application had no effect on starch content of *Mgingqeni*, whereas it decreased starch content of *Pitshi*. When fertilizer was not applied, *Pitshi* showed higher starch content than *Mgingqeni* but not *Dumbe-dumbe,* which was also not significantly different from *Mgingqeni*. *Pitshi* showed lower starch content than *Dumbe-dumbe* and *Mgingqeni*, which were not different from each other when 160 kg ha^{-1} of N were applied. There was no significant difference between starch content of the cultivars when 320 kg ha^{-1} of N fertilizer was applied.

In the storage experiment, starch content was significantly (*P<0.001*) affected by the interaction of temperature, packaging, cultivar and sampling month. Starch content generally decreased with time in storage. Ambient temperature generally showed higher starch content than 12℃ (Table 2). Cormels packaged in me sh bags and *Dumbe-dumbe* also displayed higher starch content compared with those packaged in polyethylene bags and boxes; and *Mgingqeni* and *Pitshi,* respectively.

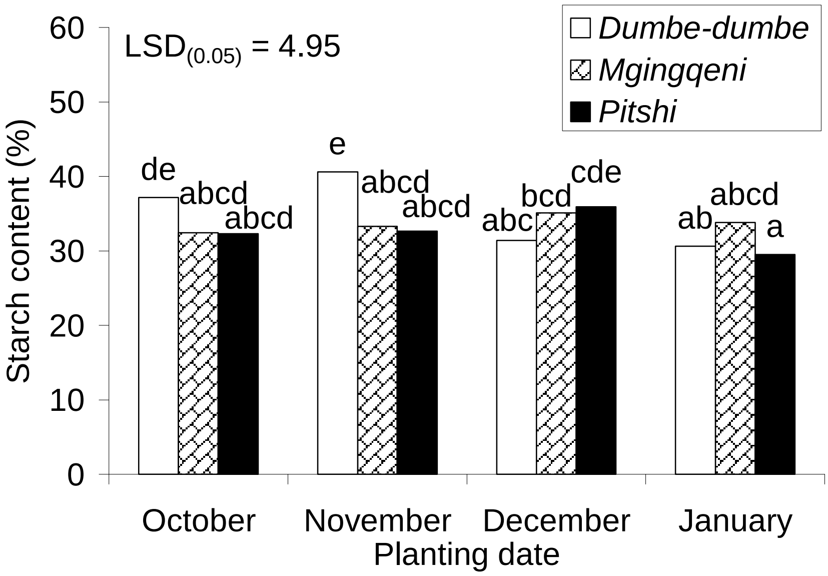

Figure 3. Starch content of taro cultivars planted at different planting dates averaged across Gromor Accelerator® application rates at Ukulinga.

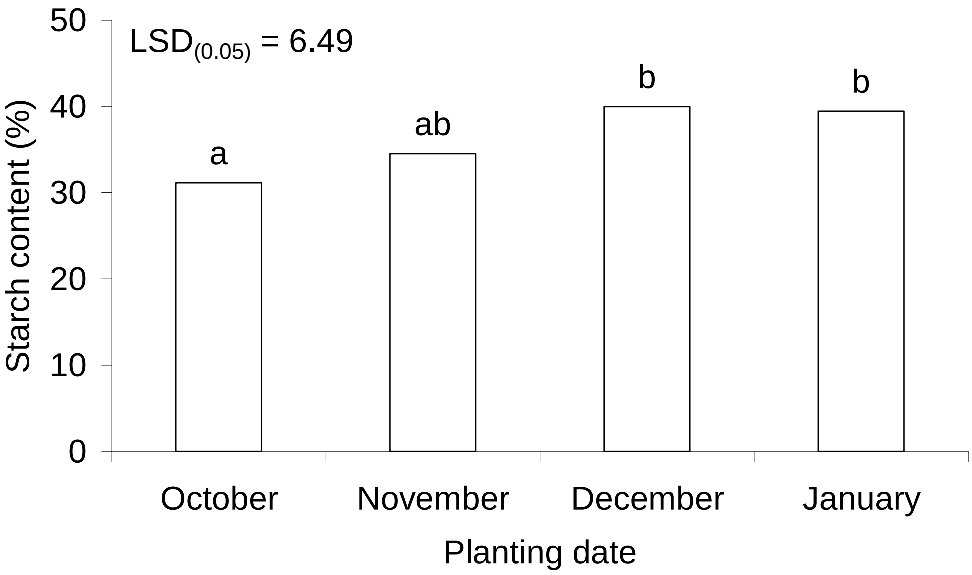

Figure 4. Starch content of taro cultivar planted at different planting dates at Umbumbulu.

DISCUSSION

Application of fertilizer had no effect on reducing sugars when taro was planted early in the season in October, November and December at Ukulinga. The findings are in line with what was found by Sharma and Arora (1988) in which applied nitrogen did not affect the sugar content of potato tubers. A negative impact of applying fertilizer on reducing sugars was evident when taro was planted in January. According to Long et al. (2004), genotype is the major factor that influenced sugar content in potatoes. This might also be true for taro since application of fertilizer had no effect on reducing sugars of *Dumbe-dumbe* and increased reducing sugars of *Mgingqeni*, whereas they were increased for *Pitshi* when 160 kg ha^{-1} of N fertilizer was applied. This is also in line with what was reported that sugar content is highly varied between cultivars (Lisińska and Laszczyński, 1989). Water

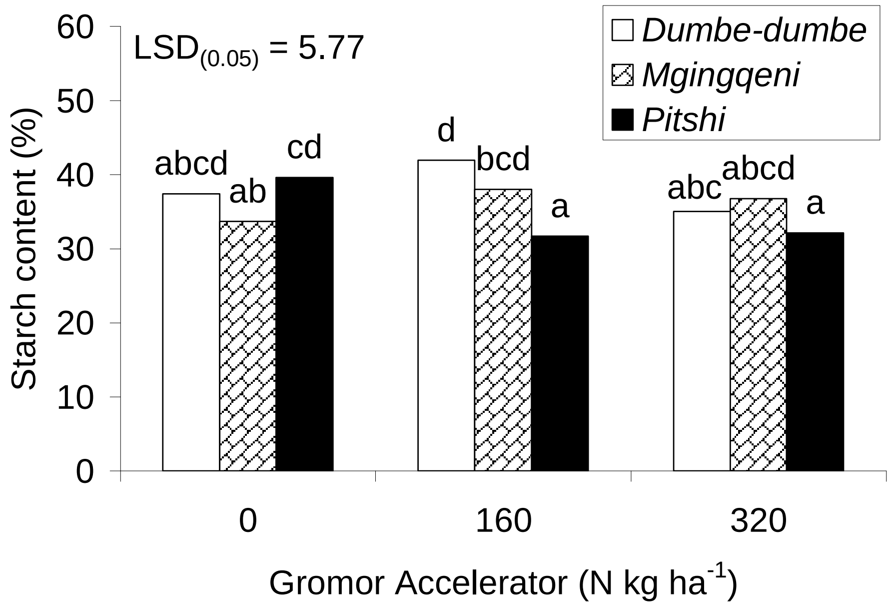

Figure 5. Starch content of taro landraces planted with different Gromor Accelerator® application rates averaged across planting dates at Umbumbulu.

Table 2. Starch content of taro cultivars stored at different temperatures in different packaging materials. Means of the interaction effect within columns (LSD $_{(0.05)}$ = 0.37) followed by the same letter are not significantly different.

Temperature	Packaging	Cultivar	Months after storage			
			1	2	3	4
12℃	Polyethylene	*Dumbe-dumbe*	36.44 i	33.52 j	30.42 i	29.06 k
		Mgingqeni	32.25 fg	31.22 g	27.08 f	26.39 g
		Pitshi	30.65 d	29.67 e	23.21 b	25.54 f
	Box	*Dumbe-dumbe*	36.40 hi	27.88c	27.63 g	26.82 h
		Mgingqeni	32.39 fg	31.72h	26.86 ef	24.36 e
		Pitshi	25.65 a	24.89 a	17.12 a	14.64 a
	Mesh bag	*Dumbe-dumbe*	36.21 hi	34.99 l	36.67 l	32.73 m
		Mgingqeni	32.09 f	31.45gh	30.88 j	27.76 j
		Pitshi	30.14 c	25.24 a	23.41 bc	22.34 d
Ambient temperature	Polyethylene	*Dumbe-dumbe*	37.14 j	33.13 i	28.40 h	27.24 i
		Mgingqeni	32.47 g	31.44 gh	30.98 j	26.37 g
		Pitshi	31.51 e	30.85 f	27.79 g	26.30 g
	Box	*Dumbe-dumbe*	36.06 h	30.55 f	30.31 i	27.24 i
		Mgingqeni	28.78 b	27.44 b	26.21 d	19.98 c
		Pitshi	30.32 cd	29.93 e	23.72 c	18.36 b
	Mesh bag	*Dumbe-dumbe*	36.18 hi	33.94 k	32.35 k	31.86 l
		Mgingqeni	32.21 fg	30.72 f	27.98 g	27.58 ij
		Pitshi	31.26 e	29.24 d	26.51 de	25.90 f

deficiency led to high sugar content (Davies et al., 1989; Ilin et al., 1997). This was evident at Umbumbulu where reducing sugars generally increased with delay in planting since it was observed that lower rainfall was experienced late in the season.

Starch content at Ukulinga was negatively impacted by delay in planting. This may be related to the fact that earlier planted taro experienced higher rainfall during the first months of corm bulking and lower temperatures during maturation as mentioned by Smith (1987) that adequate moisture results in high starch content in potatoes. Starch content of *Dumbe-dumbe* significantly decreased when planting was delayed by two months, whereas in *Pitshi* it decreased to the level not significantly different from those of October and November planting; and *Mgingqeni* was not affected by planting date. The different responses of the taro landraces confirmed what was reported by Willis et al. (1983), that starch properties in taro are influenced by genetic variation. Applying fertilizer negatively affected starch content of *Pitshi* at Umbumbulu. This seems to suggest that increasing nitrogen fertilizer rates significantly decreases starch content as stated by Sharma and Arora (1988) and Shan et al. (2004). *Mgingqeni* was, however, not affected by increasing nitrogen.

Reducing sugars seemed to have decreased before storage and this might have been a result of keeping corms in mesh bags at ambient temperature before storage as it was reported by Heinze et al. (1955) and Kirkpatrick et al. (1956), that reducing sugars can be lowered by holding tubers at 21℃. Starch decreased progressively over storage time while sugars increased (Rivero et al., 2003). This is confirmed by the findings of the present study that also showed decreasing starch content and increasing reducing sugars with time in storage. The shelf life of root crops is said to be influenced by genotype, storage temperature and packaging (Kay, 1987; Brown et al., 1990; Yosuke et al., 2000). This was also true with taro. Starch content of taro corms was found to be higher at ambient temperature compared to 12℃, whereas reducing sugars were higher at 12℃ a s compared to ambient temperature. It was also reported by Williams and Cobb (1993), Wiltshire and Cobb (1996), Wong Yen Cheong and Govinden (1998), Yosuke et al. (2000) and Pal et al. (2008) that low temperature storage causes tubers to develop reducing sugars and decrease starch content, which makes them unsuitable for processing into crisps.

It was also found in this study that cormels stored in the mesh bag had the higher starch content whereas those in open box had the higher reducing sugars. This might have been due to the fact that the mesh bag somehow warmed the taro cormels and those stored in the box were more exposed to lower temperature especially at 12℃. The higher starch content and reducing sugars displayed by *Dumbe-dumbe* compared to other landraces might have been due to the landrace naturally having higher starch content than *Mgingqeni* and *Pitshi,* and even if it develops more reducing sugars, a large proportion of starch remains at the end.

Conclusions

The study showed that delaying planting reduced starch content for *Dumbe-dumbe* and *Pitshi* at Ukulinga. Delaying planting decreased reducing sugars when no fertilizer was applied and application of 320 kg ha^{-1} N increased reducing sugar content. *Dumbe-dumbe* had high reducing sugars when no fertilizer was applied. In *Mgingqeni,* reducing sugars were increased by fertilesation. At Umbumbulu, fertilisations decreased starch content of Pitshi only and delay in planting increased sugar content for *Dumbe-dumbe* and decreased it for *Mgingqeni*and *Pitshi.* Starch of taro corms decreased and reducing sugars increased with time in storage. Low temperature decreased starch content while it increased reducing sugars. Mesh bags had higher starch content while open boxes had higher reducing sugars. *Dumbe-dumbe* had higher starch content and higher reducing sugars.

It is recommended that *Dumbe-dumbe* be planted in October and November without fertilizer at Ukulinga and the same landrace be planted with low fertilizer in October at Umbumbulu. It is also recommended that taro cormels be stored at 12℃ for two months and at amb ient temperature for four months to maintain the acceptable level of reducing sugars for crisp making. Genetic analysis of the differences between landraces is necessary for future studies.

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