Asian Journal of Plant Sciences

ISSN 1682-3974

Asian Journal of Plant Sciences 9 (8): 463-470, 2010
ISSN 1682-3974

Carbohydrate Characters of Six Vegetable Waxy Corn varieties as Affected by Harvest Time and Storage Duration

S. Simla, K. Lertrat and B. Suriharn
Department of Plant Science and Agricultural Resources, Faculty of Agriculture,
Khon Kean University, Khon Kaen 40002, Thailand

Abstract: Six varieties of vegetable waxy corn (*Zea mays* var. *ceratina*) popular among growers and consumers in Thailand were analyzed for their carbohydrate compositions at different harvest times from 15 days after Pollination (DAP) to maturity and a corn variety was stored at different durations. All sugar compositions increased with Days after Pollination (DAP) to the peak and then declined, whereas total starch, amylopectin and phytoglycogen compositions increased with DAP and were highest in mature kernels. The accumulation timings of carbohydrate compositions were different among varieties and compositions. Suitable harvest times can vary between 17 and 25 DAP. The highest harvest durations were observed in Tien Baan Kao and Big White 852 being 9 and 7 days, respectively. Storage of waxy corn under ambient conditions resulted in rapid loss of sugar contents, whereas total starch, amylopectin and phytoglycogen were increased. Low storage temperature is required to maintain shelf-life of waxy corn products. These varieties are highly recommended for commercial production and can be used as germplasm sources for waxy corn improvement.

Key words: Carbohydrate composition, eating quality, immature kernel, marketable stage, small ear waxy corn, storability

INTRODUCTION

Waxy corn (*Zea mays* var. *ceratina*) is increasingly important in local market in Thailand and also important in other countries in Asia such as China, Vietnam, Laos, Korea and Taiwan (Thongnarin *et al*., 2008; Kesornkeaw *et al*., 2009). Thailand exports waxy corn hybrid seeds and frozen waxy corn and it has a promising trend for market expansion both at local and international market. However, waxy corn is inferior compared to sweet corn because it has shorter harvest period and storability. To improve quality of waxy corn, appropriate harvest times should be determined in a wide range of varieties and storability after harvest should be investigated.

Carbohydrate characters of the kernels are important factors determining table quality of waxy corn. These include sugar in forms of sucrose, glucose and fructose, phytoglycogen and starch (Creech, 1965). Sugar determines sweetness, glycogen determines tenderness and starch in the form of amylopectin determines waxy taste (Azanza *et al*., 1996). The balance of these components creates the unique taste of waxy corn that has not been found in any other types of vegetable corn.

After pollination, all forms of carbohydrate accumulate in the kernels. The rates and patterns of accumulation might be different among waxy corn varieties and therefore, these may indicate the right harvest times among waxy corn varieties.

After harvest, sugar in waxy corn kernels reduces very rapidly. Although sugar loss can be reduced with better post-harvest practices such as storage under controlled environment and reduced storage time from harvest to table (Garwood *et al*., 1976; Evensen and Boyer, 1986). Waxy corn is generally stored at ambient conditions for three days or more until it is consumed or processed because of the lack of storage and transportation facilities. A better understanding on quality loss of waxy corn after harvest should provide better strategies for maintaining quality of waxy corn and breeding for improved storability may be possible.

The objective of this study was to compare carbohydrate compositions of waxy corn at different marketable stages and physiologically-mature kernels and to investigate carbohydrate changes of waxy corn when stored under ambient conditions at different durations.

MATERIALS AND METHODS

Plant materials: Six varieties of waxy corn (Tien Baan Kao, Tien Tak-Ngai, Eight Row, Jae-Lee, Ubon and Big

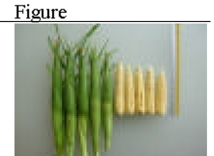
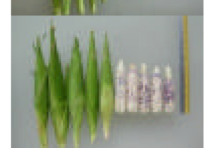
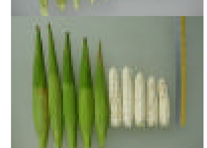
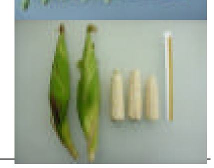
Corresponding Author: Kamol Lertrat, Department of Plant Science and Agricultural Resources, Faculty of Agriculture, Khon Kean University, Khon Kaen 40002, Thailand Tel: +66 43 202696 Fax: +66 43 202696

White 852) were selected and used in this study because they are popular in different parts of Thailand. Tien is Thai word and refers to small ear waxy corn. Tien Baan Kao is a landrace popular in the Central Plain of Thailand, especially in Pranakorn Sri Ayudtha province. It is classified as small ear waxy corn with yellow kernels and slightly sweet taste. Tien Tak-Ngai is popular in Loei province in the upper part of the Northeast Thailand. It is highly prolific and has purple kernels, stickiness, tenderness and sweetness. Eight Row is a landrace variety of waxy corn that is popular in the east region of Thailand including Prachin Buri and nearby provinces. It has eight kernel rows and good eating quality. The kernels are white and the texture is tender with slight sweetness when boiled. Jae-Lee is popular in the upper Central Plain region of Thailand especially in Nakorn Sawan province. Ubon has taper-shaped ears with white kernels. It is sticky, sweet and tender when boiled. This landrace is very popular in the lower part of the Northeast especially in Ubontachathani province. Big White is the first commercial hybrid in Thailand. It was accepted by consumers in very short time after release because of its palatable taste. This variety has medium ear size with white kernels. Most of them are landraces except for Big White 852, which is the first single-cross hybrid commercially available in Thailand, as described in Table 1.

Crop management: The corn varieties were planted in the field at the Plant Breeding Research Center for Sustainable Agriculture, Faculty of Agriculture, Khon Kaen University, Thailand (16 27 06.19 N, 102 48 46.45 E, 166 masl) from November 2007 to February 2008. Conventional tillage was practiced for soil preparation including primary plough, secondary plough, harrowing and leveling.

Cattle manure at the rate of 1875 kg ha^{-1} and a combination of chemical fertilizers (15-15-15 of N, P_2O_5 and K_2O) at the rate of 156.25 kg ha^{-1} was incorporated into the soil during soil preparation. Soil ridges at the spacing of 80 cm were built after soil preparation. Sprinkler irrigation was also made available to avoid drought stress. Each corn variety was randomly planted on 5 ridges with 5 m in length for each ridge and spacing of 25 cm between plants within each row. The seeds were over-planted and later were thinned to obtain 1 plant per hill at 14 Days after Seeding (DAS).

Table 1: Some characteristics and sources of six varieties

Varieties	Type	Source	Figure
Tien baan kao	Open-pollination variety	Ayutthaya Province	
Tien tak ngai	Open-pollination variety	Loei Province	
Eight row	Open-pollination variety	Prachinburi Province	
Ubon	Open-pollination variety	Ubon Ratchathani Province	
Jae lee	Open-pollination variety	Nakhon Sawan Province	
Big white 852	F_1 Hybrid	East-West Seed International Ltd.	

Second fertilization consisting of 156.25 kg ha^{-1} of Urea plus 156.25 kg ha^{-1} of a combination of N, P_2O_5 and K_2O formula 15-15-15 was done at 14 DAS by side dressing. Third fertilization comprising 156.25 kg ha^{-1} of N, P_2O_5 and K_2O formula 15-15-15 was done at 30 DAS and fourth fertilization at the rate of 187.5 kg ha^{-1} of N, P_2O_5 and K_2O formula 13-13-21 was done at silking. Weed control was applied when necessary. Manual pollination was done for each plot.

Five ears of uniform size were harvested for each variety at 15, 17, 19, 21, 23 and 25 Days after Pollination (DAP) and also at physiological maturity (35 days for small ear waxy corn and 40 days for normal waxy corn). The immature ears were immediately placed in ice bath in the field and then transported to the laboratory.

Tien Baan Kao was selected for storability study because it is the most popular variety in Thailand. Immature ears at 23 DAP were used for carbohydrate analysis. Each sample consisted of five uniform ears and the sample was replicated three times. The separated samples were stored under ambient conditions for 0, 1, 3, 5 and 7 days.

After predetermined storage times, the samples were placed in sealable plastic bags, put in ice bath and transported to the laboratory. In the laboratory, the ears were husked and cut at the ends. Kernels were removed from the crops with a sharp knife, sealed in plastic bags and placed in liquid nitrogen. The samples were later stored in a freezer at -20°C until used.

Carbohydrate analysis: The samples from all varieties were trawled and homogenized in a blender. Pericarp and embryo were discarded. Each sample in a quantity of 1 g was loaded in a micro-tube for extraction of sugars, phytoglycogen and starch, using different extraction solvents.

For extracting sugars, the samples were extracted with 90% ethanol in water bath (80°C). One milliliter of 90% ethanol was added in the micro-tubes containing the samples. The tubes were shaken well with vortex mixer and centrifuged at 15,000 rounds per minute (rpm) for 7 min. The extraction process was repeated three times for complete extraction of sugar. The supernatants for all extractions of the same sample were kept in the same vials and distilled water was added into the vials to obtain a total volume of 5 mL. The vials were stored in the refrigerator at -20°C for further sugar analysis.

Sugar analysis was carried out using High Performance Liquid Chromatography (HPLC) method. Briefly, standard curve of sugar compositions was first constructed by using sucrose, glucose and fructose with known concentrations. Five gram of each sugar was dissolved with distilled and de-ionized water in a volumetric flask and the volume was adjusted to 100 mL. The concentration was equivalent to 50 mg mL^{-1} and the stock was later diluted to obtain different concentrations of 5.0, 7.5, 10.0 and 25 mg mL^{-1}, respectively. The solutions were filtered through 0.45 μm nylon membrane filter with 13 mm diameter and the solutions were further used for constructing a standard curve using a HPLC machine. The HPLC consisted of a Shimadzu™ LC10AT pump, a Shimadzu™ RID 10A reflective index detector, a Shimadzu™ SIL $10AD_{VP}$ auto injector, a Water™ Temperate Control Module II and a Water™ Column Heater Module. The column is 300×6.5 mm, Sugar Pak™ with Guard Pak Holder and Guard Column insert. The mobile phase was distilled and de-ionized water previously filtered thought 0.45 μm nylon membrane filter with 47 mm in diameter and degassed prior to use. Chromatography was carried out at 90°C with a flow rate of 0.5 mL min^{-1}.

The supernatants containing extracted sugar were filtered through 0.45 μm nylon membrane filter with 13 mm diameter as described previously. A 20 μL portion of sample extract was injected to determine the amount of each sugar. The total sugar content was estimated by summing the amount of each sugar.

The pellet in the micro-tubes after extracting sugars was used for extracting glycogen. One mL of 10% ethanol was added into the micro-tubes in water bath at 80°C and the tubes were shaken well in a vortex mixer. Then, the samples were incubated in the refrigerator at 4-5°C for 12 h for better release of glycogens. The samples were centrifuged at 15,000 rpm for 10 min. The extraction process was repeated three times for complete extraction of glycogens. The supernatants for all extractions of the same sample were kept in the same vials and distilled water was added into the vials to obtain total volume of 5 mL. The vials were stored in the refrigerator at -20°C for further analysis.

Quantification of phytoglycogen was carried out using phenol-sulfuric colorimetric method according to the protocol described previously (Dubois *et al*., 1956). The pellet left in the micro-tubes after extracting glycogen was used for extracting starch. The samples were oven-dried and samples of 20 mg were loaded in test tubes. Ten milliliter of 90% dimethyl-sulfoxide was added into the test tubes and the samples were stirred well in a vortex mixer for 10 minutes. The samples were then put in a water bath at 85°C for 45 min. During water bath, the samples were stirred in a vortex mixer every 15 min. The samples were kept in ambient temperature until gelling was formed. If gelling was not formed, added some more distilled water to a volume of 25 mL. If gelling was formed, repeated the process and also extended the shaking time of the vertex and incubated time in the water bath. The samples were stored in the freezer at -20°C for further starch analysis.

Quantification of total starch was carried out using the method described previously for the quantification of phytoglycogen except for the absorbed wavelength being 600 nanometers instead of 490 nanometers.

Twenty grams each of a series of pure potato amylase and amylopectin (0, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100% amylopectin) were dissolved in 10 mL of 90% Dimethyl Sulfoxide as described previously, then 1 mL of diluted solution and 1 mL of iodine solution were added and mixed vigorously. The volume was adjusted to 10 mL with distilled water and mixed vigorously. The color was allowed to develop for 15 min, then mixed the contents of the flask by hand and measured the absorbance of the standard mixture at 600 nanometers against a reagent blank as the reference. The values were plotted on a standard curve, the regression equation for the standard curve was determined and this equation was used to calculate the total amylopectin content of the samples.

Data analysis: For the study of the effect of harvest time on eating quality, variety and harvest time were considered as random effects and replication was considered as fixed effect. The analysis of variance was performed for each character following a 6×7 factorial experiment in Completely Randomized Design (CRD) with three replications. Factor A was six waxy corn varieties and factor B was 7 harvest times.

As vegetable, corn except baby corn cannot be consumed earlier than 15 days after pollination, the evaluation was carried out from 15 days after pollination until 25 days after pollination of which harvest was normally practiced at these periods and dry mature kernels were also used for comparison. The analysis was carried out separately for each variety.

For the study of storability, variety and storage time were considered as random effects and replication was considered as fixed effect. The analysis of variance was performed for each character following a CRD with three replications.

Where F-ratio was significant, the least significant difference was calculated to compare means. All calculation were done using M-STATC software program.

RESULTS

Three groups of carbohydrate compositions were used to determine eating quality of waxy corn. These included sugar, glycogen and starch. Sugar indicates sweetness, glycogen determines tender texture of the kernels and starch especially amylopectin determines stickiness. In this study, eating quality of six waxy corn varieties was determined at different harvest times and among these varieties, one variety was chosen for the study of storability under ambient conditions because of limited financing. Further investigations are required to draw conclusive results.

Effects of harvest time on eating quality of waxy corn: In general, there were significant differences among harvest times for sucrose, glucose, fructose, total sugar, glycogen, total starch and amylopectin in all waxy corn varieties (Fig. 1a-f). Similar patterns of phytoglycogen were observed in all waxy corn varieties. Phytolycogen was found in small amount from 15 days after pollination (DAP) to 25 DAP and increased at physiological maturity (35 DAP).

As most starch in waxy corn is amylopectin, the patterns of amylopectin and the patterns of total starch were rather similar in all waxy corn varieties. Amylopectin and total starch gradually increased from 15 to 25 DAP and sharp increases in amylopectin and total starch were found from 25 DAP to physiological maturity (35 DAP). However, the increases in amylopectin and total starch among waxy corn varieties were different in magnitude. Big White 8523 had the lowest amylopectin and total starch (about 300 mg g^{-1}).

Tien baan kao: The highest sucrose (49.6 mg g^{-1} fresh weight) was found at 15 Days after Pollination (DAP) and sucrose content declined in successive evaluations until it was the lowest (9.3 mg) in mature kernels. For glucose and fructose, in contrast to sucrose, the initial contents were observed to be 18.8 and 11.5 mg, respectively, at 15 DAP and then, the contents increased until they reached the peaks at 19 DAP (27.3 and 20.8 mg for glucose and fructose, respectively). After the peak, glucose and fructose started to decline and became zero in mature kernels.

The increasing rates of glucose and fructose in Tien Ban Kao were higher than the reducing rate of sucrose at 15 to 19 DAP. Although the rates were reduced at 21 to 23 DAP, the content of mono-sugar was higher than poly-sugar from 17 to 23 DAP. As total sugar consisted of sucrose, glucose and fructose, it increased from 79.9 mg at 15 DAP to 90.0 mg at 19 DAP and then declined to 9.3 mg in mature kernels. At this stage, all sugar was sucrose.

The best period for accumulation of sugar and phytoglycogen was during 19 to 21 days after pollination. Harvest at this period could yield the best eating quality because of the highest sweetness and tenderness.

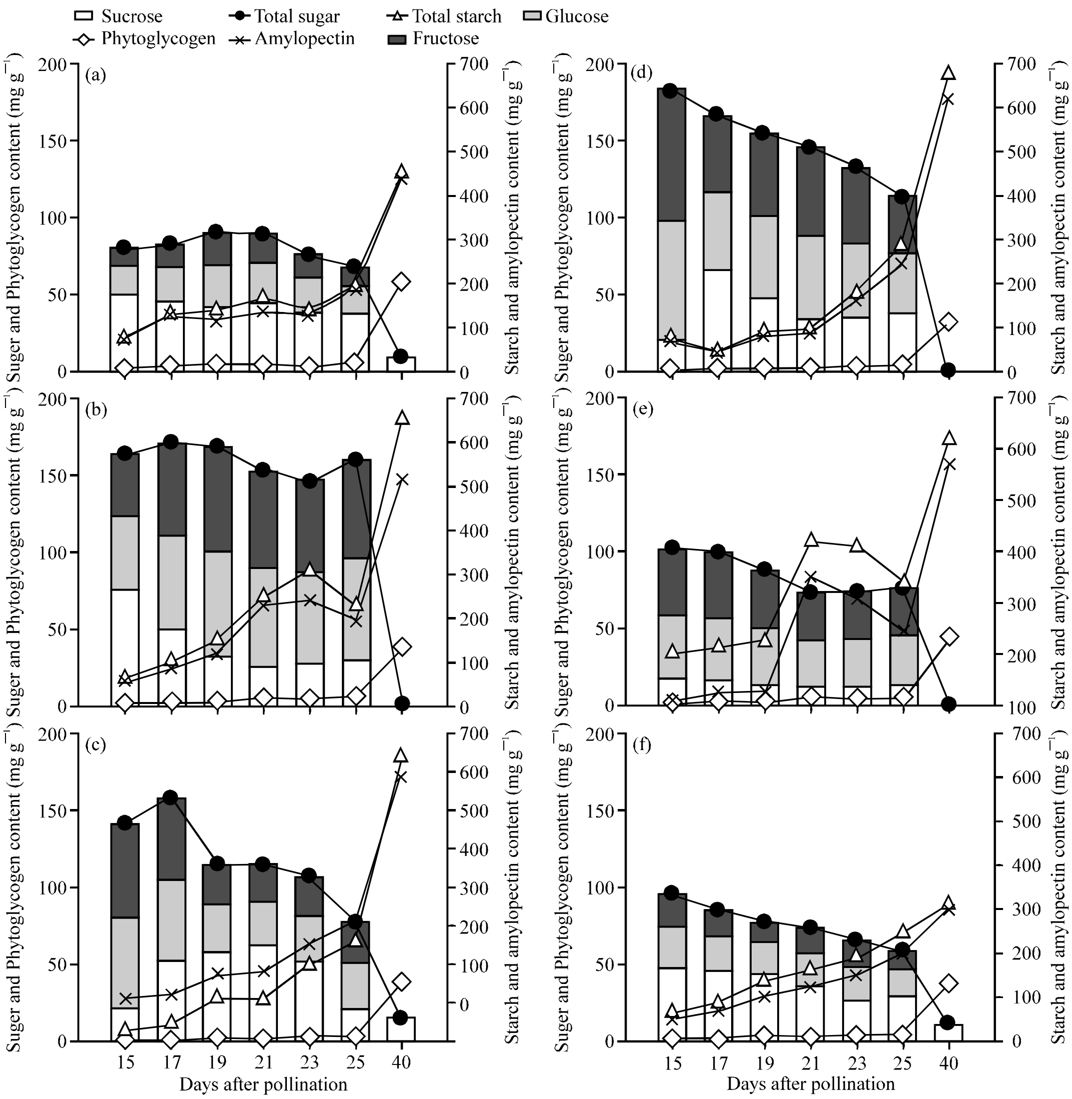


Fig. 1: Carbohydrate compositions (mg g^{-1} fresh weight) of six waxy corn varieties harvested at 15, 17, 19, 21, 23 and 25 days after pollination and at physiological maturity, (a) Tien Baan Kao, (b) Tien Tak Ngai, (c) Eight Row, (d) Jae Lee, (e) Ubon and (f) Big White 852

Harvest at 15 days after pollination could yield the lowest starch but the kernels are too young for eating. Harvest later than 21 days after pollination could result in the highest stickiness but the kernels are too mature for eating.

Tien tak-ngai: Sucrose was highest (76.2 mg) at 15 DAP and reduced with DAP until 25 DAP (37.1 mg). Sharp reduction in sucrose was found in mature kernels (1.1 mg).

Glucose and fructose started at 46.6 and 40.5 mg, respectively at 15 DAP and seemed to increase until 25 DAP. Glucose and fructose contributed a larger portion to total sugar from 15 to 25 DAP compared to sucrose. As sucrose reduced at successive evaluations, glucose and fructose seemed to increase, making sugar content more stable across immature stages and total sugar at immature stages was about two folds higher than that of Tien Ban Kao (varied between 145.0 to 170.4 mg). However, sucrose in mature kernels was very low (1.1 mg) and glucose and fructose became zero.

The most appropriate harvest time for Tien Tak-Ngai would be at 19 days after pollination when the accumulation of sugar was the highest and phytoglycogen was not significantly different from the peak at 25 days after pollination. Because of its high sugar, harvest of Tien Tak-Ngai can be expanded between 17 to 25 DAP without significant loss of its quality.

Eight row: Sucrose started with low concentration (21.6 mg) at 15 DAP, increased with DAP, peaked at 21 DAP (62.4 mg) and then turned to reduce to the lowest content (15.0 mg) in mature kernels. Glucose and fructose started with high concentrations (58.8 and 60.8 mg, respectively) and gradually reduced with DAP. Finally, glucose and fructose became zero in mature kernels.

Glucose and fructose constituted a larger portion at 15, 17 and 25 days after pollination, but sucrose was dominant at 19-23 days after pollination which was the period most suitable for harvest because of higher sweetness.

Harvest at 21 DAP is the most appropriate because of high sweetness and medium phytoglycogen and starch. Harvest at 17 DAP could yield the highest sweetness but the ears were too young.

Jae-Lee: Glucose, fructose and total sugar were the highest at 15 DAP and got reduced with DAP. Sucrose, in contrast, increased with DAP and peaked at 19 DAP. Sucrose got reduced after 19 DAP and was the lowest in mature kernels.

Harvest at 19-21 DAP was the most appropriate because of medium sugar and phytoglycogen contents and low starch content. Harvest at 15-17 DAP could yield the highest sweetness but the ears were too young.

Ubon: Sucrose, fructose, glucose and total sugar were the highest at 15 DAP and reduced in the successive harvest times. The highest total sugar (101.8 mg) was found at 15 DAP and the value become zero in mature kernels. Fructose and glucose comprised a large portion at eatable stages.

The appropriate harvest time would be at 21 DAP. Although total sugar was low at this stage, phytoglycogen (5.0 mg) and amylopectin (350.4 mg) were high and total starch was medium (372.8 mg), making the kernels more suitable for consumption than at 15 DAP when the ears are too young.

Big white 852: The highest sucrose (47.5 mg), glucose (26.7 mg), fructose (21.0 mg) and total sugar (95.3 mg) were observed at 15 DAP. All sugar characters gradually reduced in successive harvests and were lowest in mature kernels. Glucose became zero in mature kernels, fructose was negligible (1.1 mg) and sucrose was the lowest (9.8 mg). As the reductions of glucose and fructose were faster than that of sucrose, at marketable stage, sucrose contributed to a larger portion than did glucose and fructose.

Based on carbohydrate characters of waxy corn, Big white 852 could be harvested at 19 to 25 DAP. For premium quality, the harvest should not be later than 21 DAP.

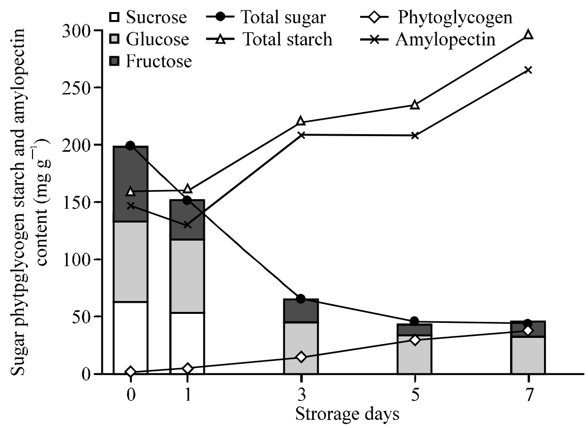


Fig. 2: Carbohydrate compositions (mg g^{-1} fresh weight) of small ear waxy corn variety '*Tien* Baan Kao' harvested at optimum market maturity and stored under ambient conditions for 0, 1, 3, 5 and 7 days

Effects of storage duration on eating quality of waxy corn: Tien Baan Kao was selected for the storability study. Under ambient conditions, storage times significantly affected sucrose, glucose, fructose, total sugar, phytoglycogen, total starch and amylopectin (Fig. 2). Sucrose was sharply reduced and depleted within three days of storage. The reductions in glucose and fructose were slower than that of sucrose and after seven days of storage, the remaining glucose and fructose became 32.9 and 13.2 mg, respectively, compared to initial glucose and fructose of 75.4 and 59.0 mg at the 0 day of storage.

In contrast to sugar, storage times significantly increased phytoglycogen, total starch and amylopectin. After 7 days of storage, phytoglycogen, total starch and amylopectin were the highest, becoming 38.36, 296.30 and 264.8 mg, respectively, compared to 2.4, 158.5 and 146.6 mg of initial values at 0 day of storage.

DISCUSSION

A better understanding on the changes in carbohydrate compositions determining eating quality of waxy corn during carbohydrate accumulation period is important in determining the appropriate times for harvest and selecting suitable corn varieties for commercial production. In addition to yield, the varieties should be of high eating quality and long durations of appropriate harvest times.

In this investigation, six waxy corn varieties differed in their carbohydrate accumulation patterns for all carbohydrate components including sucrose, glucose, fructose, total sugar, phytoglycogen, total starch and amylopectin. As these carbohydrate compositions determine eating quality of waxy corn, these varieties also differed in their appropriate harvest times.

The appropriate harvest times would be as early as 17 Days after Pollination (DAP) to 25 DAP, depending on varieties and the durations of the appropriate harvest times also varied from 3 days to 9 days depending on varieties. The pods are too young when they are harvested earlier than 17 DAP and are over-mature when they are harvested later than 25 DAP. Tien Baan Kao, Big White 852 and Eight Row were the best varieties for long durations of appropriate harvest times, respectively, in the descending order of 9, 7 and 5 days. These varieties are promising germplasm sources for improving waxy corn for long durations of harvest maturity.

Present findings supported the previous results carried out in sweet corn and normal maize in relation to the variations in carbohydrate accumulation patterns (Laughnan, 1953; Creech, 1965; Creech and McArdle, 1966; Ayers and Creech, 1969). Similarly, Ferguson *et al.* (1979) and Shaw and Dickinson (1984) also individually reported that sugar contents increased from pollination to the peak, then declined and were the lowest in dry and physiologically mature kernels. This trend is also found in the report of Xu *et al.* (2010).

Although the patterns of carbohydrate accumulation were similar for most studies, the timings of carbohydrate accumulation were genotype-dependent for all carbohydrate components for both before peak and after peak. Cameron and Cole (1959) and Creech (1965) demonstrated in sweet corn that corn genotypes sh_2 and bt had low reduction in sugar content than did corn genotypes with su. In our study, the genotypes evaluated were common in wx gene and other genes controlling sugar characters but they still differed in sugar content reduction after peak. Therefore, improving waxy corn varieties with lower reduction in sugar content after peak via conventional breeding might be possible.

The accumulation of phytoglycogen and total starch is dependent on types of corn (Chander *et al.*, 2008). The ranks of phytoglycogen accumulation could be arranged in descending orders as su>wx>sh_2, and for total starch, the descending orders would be wx>su>sh_2 (Cameron and Cole, 1959; Creech, 1965; Creech, 1968). The accumulation of total starch is towards the peak in physiologically mature kernel (Xu *et al.*, 2010), while the accumulation of phytoglycogen has two contrasting patterns; peak in dry mature kernels and peak before physiological maturity (Creech, 1965).

As amylopectin constitutes more than 80% of total starch of waxy corn, this composition creates the unique sticky taste that is different from other vegetable corns. Therefore, starch is considered to be an important factor determining eating quality of waxy corn. Additionally, it is important to note here that good eating quality needs balance compositions of carbohydrate rather than the extreme for each composition together with balance glassy flavors of corn and mouth feel. In addition to these criteria, the kernels should be at milky stage (R4). Harvest at 15 DAP was too early and the kernels are not eatable although sugar content was the highest, while harvest later than 25 DAP resulted in high starch and phytoglycogen but low sugar content.

As mentioned earlier, the harvest times of Tien Baan Kao could be extended to 9 days without significant loss in its quality. It was selected for storability study under ambient conditions. Rapid reductions in sucrose, glucose and fructose were found after few days of storage and sucrose was not detected at the end of storage. This could be due to the changes in carbohydrate compositions via metabolic process in which invertase enzyme plays an important role. In this process, sucrose is first transformed in to glucose and fructose, respectively and this is why sucrose was depleted more rapid than glucose and fructose. Further investigations in other varieties are still required to draw more conclusive results.

Similar results were clearly demonstrated in sweet corn. Sugar content was reduced to more than 50% within 24 h of storage at 27°C, while only 1/3 of total sugar was reduced after storage for 96 h at 4°C (Garwood *et al.*, 1976; Carey *et al.*, 1982; Evensen and Boyer, 1986). This emphasizes the importance of low temperature in maintaining eating quality of corn products and extends the shelf life of the products.

In contrast to sugar content, starch and phytoglycogen increased with times of storage. This is because sugar is converted in to starch pre-cursors and the lack of class-one mutant that inhibits starch synthesis in waxy corn causes rapid accumulation of starch and phytoglycogen (Tracy, 2001). The patterns of starch and phytoglycogen accumulation during storage were similar to those reported in sweet corn and storage at low temperature could considerably reduce sugar loss (Garwood *et al.*, 1976; Evensen and Boyer, 1986).

In conclusion, different compositions of carbohydrate in waxy corn accumulated differently during immature stages. The suitable harvest times differed among varieties and the durations were also different. Harvest at 17 to 25 days after pollination is the best for good eating quality. Tien Baan Kao and Big White 852 are highly recommended for commercial production because of their good eating quality and long durations of marketable maturity. They are also the promising germplasm sources of waxy corn improvement. Storage of waxy corn under ambient conditions resulted in rapid loss of sugar contents. Storage under controlled temperatures could improve storability of waxy corn and further postharvest investigations are still required.

ACKNOWLEDGMENTS

We are grateful for the financial support provided by the University Staff Development Program, Mahasarakham University, the Commission on Higher Education, Thailand (Grant No. 028/2548), to the National Center for Genetic Engineering and Biotechnology, Bangkok, Thailand (Grant No. BT-B-01-PT-12-5140) and the Plant Breeding Research Center for Sustainable Agriculture, Faculty of Agriculture, Khon Kaen, Thailand (Grant No. PBRCSA01/2548). Mr. Thawan Kesmala is also acknowledged for his critical reading and valuable comments during manuscript preparation.

REFERENCES

Ayers, J.E. and R.G. Creech, 1969. Genetic control of phytoglycogen accumulation in maize (*Zea mays* L.). Crop Sci., 9: 739-741.

Azanza, F., B.P. Klein and J.A. Juvik, 1996. Sensory characterization of sweet corn lines differing in physical and chemical composition. Food Sci., 61: 253-257.

Cameron, J.W. and D.A. Cole, Jr., 1959. Effects of the genes su_1, su_2 and *du* on carbohydrates in developing maize kernels. Agron. J., 51: 424-427.

Carey, E.E., A.M. Rhodes and D.B. Dickinson, 1982. Postharvest levels of sugars and sorbitol in sugary enhancer (su se) and sugary (su Se) maize. Hortic. Sci., 17: 241-242.

Chander, S., Y. Meng, Y. Zhang, J. Yan and J. Li, 2008. Comparison of nutritional traits variability in selected eighty-seven inbreds from Chinese maize (*Zea mays* L.) germplasm. J. Agric. Food Chem., 56: 6506-6511.

Creech, R.G., 1965. Genetic control of carbohydrate synthesis in maize endosperm. Genetics, 52: 1175-1186.

Creech, R.G. and F.J. McArdle, 1966. Gene interaction for quantitative changes in carbohydrates in maize kernels. Crop Sci., 6: 192-194.

Creech, R.G., 1968. Carbohydrate synthesis in maize. Adv. Agron., 20: 275-322.

Dubois, M., K. Gills, J.K Hamilton, P.A. Rebers and F. Smith, 1956. A colorimetric method for determination of sugars and related substances. Anal. Chem., 28: 350-356.

Evensen, K.B. and C.D. Boyer, 1986. Carbohydrate composition and sensory quality of fresh and stored sweet corn. J. Am. Soc. Hortic. Sci., 111: 734-738.

Ferguson, J.E., D.B. Dickson and A.M. Rhodes, 1979. Analysis of endosperm sugars in a sweet corn inbred (Illinois677a) which contains the sugary enhancer (se) gene and comparison of se with other corn genotypes. Plant Physiol., 63: 416-420.

Garwood, D.L., F.J. McArdle, S.F. Vanderslice and J.C. Shannon, 1976. Postharvest carbohydrate transformations and processed quality of high sugar maize genotype. J. Am. Soc. Hortic. Sci., 101: 400-404.

Kesornkeaw, P., K. Lertrat and B. Suriharn, 2009. Response to four cycles of mass selection for prolificacy at low and high population densities in small ear waxy corn. Asian J. Plant Sci., 8: 425-432.

Laughnan, J.R., 1953. The effect of the sh2 factor on carbohydrate reserves in the mature endosperm of maize. Genetics, 38: 485-499.

Shaw, J.R. and D.B. Dickinson, 1984. Studies of sugars and sorbitol in developing corn kernels. Plant Physiol., M75: 207-211.

Thongnarin, N., K. Lertrat and S. Techawongstien, 2008. Combining ability study in waxy corn (*Zea mays* var. *ceritina*) inbred lines. Acta Hortic., 769: 151-156.

Tracy, W.F., 2001. Sweet Corn. In: Specialty Corns, Hallauer, A.R. (Ed.). 2nd Edn., CRC Press, Boca Raton, USA., pp: 155-197.

Xu, J.G., Q.P. Hu, X.D. Wang, J.Y. Luo, Y. Liu and C.R. Tian, 2010. Changes in the main nutrients, phytochemicals and antioxidant activity in yellow corn grain during maturation. J. Agric. Food Chem., 58: 5751-5756.