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Effects of Harvest Time and Duration before Cooling on the Post-Harvest Quality and Shelf-life Stability of French Bean (*Phaseolus vulgaris* L.)

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Abstract

Post-harvest handling of French beans is very critical in ensuring acceptable quality in the market. The time of harvesting and duration between harvesting and cooling are very important. Further, long distances between growing fields and cooling facilities provide challenges to growers. This study was carried out to evaluate the effects of harvest time and duration before cooling on the post-harvest quality and shelf-life stability of French beans. Five harvesting times were evaluated including 7 am, 9 am, 11 am, 1 pm and 3 pm. The harvested beans were then subjected to five different durations before start of cooling; 0 hr, 2 hours, 4 hours, 6 hours and 8 hours. The proximate compositions of the fresh French beans samples were determined using standard methods. The results show that samples had the following ranges of proximate parameters: 2.1-2.4 g/100 g protein, 0.8-1.0 g/100 g fiber, 0.8-1.6 g/100 g ash, 88-92% moisture, 0.14-0.15 fat, and 6.1-7.6 g/100 g carbohydrate and with 3% change in weight for samples harvested late in the afternoon. The study revealed a significant loss of moisture and weight for every delay in start of cooling while there was marginal increase in protein, fat and ash contents. Speed of deterioration of the products may be reduced by reducing the duration between harvesting and cooling for a period of not more than two hours.

Keywords: Postharvest quality; Shelf life stability; Harvesting time; Duration before cooling; *Phaseolus vulgaris* L; Nutritional qualities

Introduction

French bean (*Phaseolus vulgaris* L.) is an important leguminous crop mostly grown as green vegetable in Kenya mainly for export markets. It is a nutritious vegetable high in vitamin C, and dietary fibers, carbohydrates, proteins and minerals [1]. The immature pods, tender parts and also dry beans are used as curry and are served fresh in salads but in most cases prepared as cooked vegetables [1]. Green beans are generally harvested at physiologically immature stage when their growth and respiration is rapid even when the temperatures are low [2]. Therefore, quality may diminish rapidly and actions must be taken to avert such crises. The quality of French beans pods depends on pre and post-harvest factors like area of production, variety, post-harvest handling, maturity stage, harvesting, cool chain management and storage conditions. Therefore, harvesting of pods at the optimum stage of maturity is important so as to ensure optimum quality and yields. The harvesting stage depends on the intended customer and is primarily determined by the pod diameter. Delayed harvesting results in loss of yield due to over-growth of pods and seeding. The ideal stage is to harvest when the pods are tender and crispy and seeds are immature. Therefore, harvesting of bean pods at the optimum stage of maturity is important as harvesting either at early or late stage results in lower yields with poor quality of pods.

Like many of the horticultural crops, French beans are perishable and depreciate in quality very fast after harvest and therefore high post harvest losses are incurred [3]. Delays in between harvesting and cooling can result in direct losses; however, the extent of these losses depends on the commodity condition at harvest and the product temperature, which can be higher than ambient temperature. The high perishability of the French beans demands an effective and uninterrupted cold chain process. It is recommended that French beans are stored at temperatures of 7–8°C. Due to the short harvest period of French beans, proper processing and storage are essential to reduce post harvest loses and to increase the shelf life [4]. Appropriate storage temperature retains the flavor and other sensory attributes important for marketing of French beans. Quality is important as many consumers consider vegetables that are firm, with good flavor and high nutritive value as having good quality. The objective of this study was to evaluate the effect of harvest time and duration before cooling on the post-harvest quality and shelf-life stability of French beans.

Materials and Methods

Experimental design and layout

This study was conducted in Naivasha, Nakuru County Kenya. Naivasha is located Latitude 0°43′ 0″ S, and Longitude 36°26′ 0″ E, a leading region in horticultural production for export and local market. French bean pods were harvested from a commercial planting at five different times during the day 7 am, 9 am, 11 am, 1 pm, and 3 pm. The harvested pods were later subjected to different pre-cooling durations of 0 hours, 2 hours, 4 hours, 6 hours and 8 hours. The beans were harvested in a perforated tray and later moved to a field shed constructed from iron sheet roofing. The harvested beans were later packed into netted bags and weighed. Temperature of the beans and weight were recorded after an interval of every 2 hours interval. The ambient temperature was also recorded after every 2 hours. A split plot design was used to assess the effects of harvest time and pre-cooling duration on the quality

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and shelf-life of French beans. Harvested beans were packed into 500 g modified atmospheric packaging (MAP) bags and were kept at temperatures between 4 and 8^{0}C and later transferred to the laboratory for proximate analysis.

Analysis of French bean samples

Determination of French bean moisture content and weight loss: Moisture content was determined by oven drying methods according to the Association of Official Analytical Chemists (AOAC) International [5]. Method 970.30. Samples were dried in an oven at 105°C for 3 hours after which the samples were cooled in a desiccator for 10 minutes. Moisture content was calculated as the loss in weight expressed as a percent of the original weight of the French bean samples. The moisture loss was represented as % of the original weight. Loss of weight was determined by weighing samples every two hours. Initial weight of the sample was noted immediately after harvest and packing into the netted bag, and again after every two hours as long as the sample was still in the field shed awaiting delivery to the cold room. The samples were weighed after every two hours using digital weighing scale (Sartorius, Ag Germany). Physiological Loss in Weight (PLW) was calculated using standard procedure as mentioned in AOAC [5].

$$\text{PLW}(\%) = \frac{\text{Initial weight - Final weight}}{\text{Initial weight}} \times 100$$

The proximate analysis of French bean samples

The dry matter content in French beans was determined according to ISO 6496, 2008. Samples were dried for half an hour at 103 ± 3°C temperature, after which they were cooled to room temperature in a desiccator. About 5 g sample was placed in a container and put in the drying oven at 103°C for 4.0 hours then the container lid was put on, sample was removed from oven and cooled in a desiccator to room temperature. Samples were weighed and dry matter content was calculated (ISO 6496, 2008). Energetic Value was calculated based on Atawer conversion factors, which considers 4 kcal/g of protein, 4 kcal/g of carbohydrate and 9 kcal/g of lipid. Carbohydrate content was calculated by subtracting water, protein, crude fiber and ashes from a 100 mg French bean sample.

Determination of crude protein (CP) and ash content in French beans: Crude protein was determined by the Kjeldahl method [5] Method 991.20. The weighed samples were placed in the micro-Kjeldahl digestion tubes then 10 ml concentrated nitrogen free sulphuric acid was added together with one selenium tablet as a catalyst per tube Njoroge et al. The samples were then digested in a DK20S digester (VelpScientifica, Bohemia, Italy) at 445°C for 3 hours. The products of digestion were distilled using the Kjeldahl distillation unit. The distillate was collected in a 15 ml 0.1 M HCl with a mixed indicator of methyl red plus methylene blue. The excess HCl was titrated against 0.1 M NaOH. Then the crude protein (CP) was calculated as;

$$\text{Crude protein (g/100 g)} = \frac{(V_1 - V_2) \times (M \times 1.4 \times 6.25)}{W} \quad [6]$$

Where V_2 is volume of HCl used for test portion, V_1 is volume of HCl acid used for blank test, M is molarity of acid, W is weight of test portion and 6.25 is the conversion factor. Ash content was determined according to ISO 5984:2002/Cor1:2005, where by the samples were incinerated in a furnace at 525°C for four hours until constant weight was obtained [5].

Determination of crude fiber content in French beans: Crude fiber content was determined by gravimetric method according to AOAC International [5], Method 984.04. About 5 g of the samples was mixed with 25 ml of 2.04 M H_2SO_4 (acid) and distilled water used to top up the contents to about 200 ml. The mixture was then digested using a digester model DK-20S digester from VelpScientifica, Bohemia, Italy at 445°C for 30 min. A glass wool rolled at the ends of the filtering stick was inserted in the suction pump to obtain the filtrate. The second digestion was done using 1.78M NaOH with similar treatment while the final digestion washing was done in 70% ethanol and the product transferred to weighed crucibles for drying at 105°C for 3 hours in an oven. Weight of the contents was recorded after the 3 h and then ashing was done in a muffle furnace at 550°C overnight and weights recorded. Crude fiber was then calculated as the difference between sample weights from furnace and that of oven.

$$\text{Crude Fiber (g/100 g)} = \frac{\text{Residue weight from oven - weight from ashing}}{\text{original sample weight}}$$

Determination of crude fat content in French beans: Crude fat content was determined as per AOAC [5] guidelines. Five grams of the samples were weighted and powdered then extracted with 10 mL of hexane for the period of 24 hours. After 24 hours, the extract was filtered with filter paper and the filtrate was evaporated on 40°C. The obtained oil was poured in amber colored 5 mL bottles and was kept on +4°C until the analysis time.

Statistical analysis

The parameters studied were physiological loss in weight, crude protein, fat content, carbohydrate, cruse ash content, salt and moisture content. Statistical analyses were conducted using Genstat version 15 (Lawes Agricultural Trust, Rothamsted Experimental Station, UK). Analysis of variance and Turkey's multiple range tests were used to compare significant differences in time of harvesting and duration before cooling and their interaction. Means were computed and tested at 5 percent level of significance.

Results

Effect of harvest time and duration before cooling on moisture content, dry matter and gross energy of French bean

French beans harvested early in the morning had the highest moisture content (90%) while those that were harvested mid-morning had the least moisture content (87%) (Table 1). The moisture content was not significantly different ($p \leq 0.05$) for each harvesting time and duration before cooling period. The different harvesting times resulted in different amount of moisture content with those harvested late in the afternoon having the least moisture content while those harvested in the morning had the highest moisture content (90%). The dry matter content of French bean samples harvested at different times and with different time delays before cooling significantly differed ($p \leq 0.05$). French beans harvested late in the afternoon and which were subjected to more than four hours before cooling had the highest dry matter content while those that were harvested in the morning (7 and 9 am) and were subjected to more than four hours before cooling recorded the least dry matter content. Harvesting time and duration before cooling had significant effect on the gross energy of French bean samples ($p \leq 0.05$). French bean samples harvested between 9 and 11 am had the highest gross energy while those harvested in the early morning and late in the afternoon had the least gross energy.

Effect of harvest time duration before cooling on nutritional quality of French bean

The results related to changes in protein content, fat content and total carbohydrate depending on the time of harvesting and duration before cooling are presented in Table 2. The protein content ranged from 2.2 g/100 g and 2.6 g/100 g, which was above the normal market expected of 2.1 g/100 g. Beans harvested later early in the morning and later afternoon had significantly higher average protein content ($p \leq 0.05$) compared to those harvested at 11 am. The protein content of various samples harvested at different times and cooled after various times were not significantly different ($p \leq 0.05$), except for those harvested at 11 am, which had slightly lower protein content compared to the rest harvesting times. The lowest protein content of French beans harvested at 9 am and 11 am cooled in two hours and four hours respectively (1.8 g/100 g) while the highest protein content was computed with samples harvested at 9 am and 1 pm (2.6 g/100 g) Averagely for all the durations before cooling, French bean samples harvested late in the afternoon recorded higher protein content when compared with those harvested early in the morning. An increase in protein content of the sample on a wet weight basis was observed in French beans samples that were harvested in the afternoon (2.4 g/100 g). The protein content of freshly beans and those kept over various durations before cooling was found to be similar, the slight variations that were observed were found to be statistically insignificant ($p \geq 0.05$). The fat content of freshly harvested French beans and precooled treated beans was found to be similar, the slight variations observed between the precooling times and different harvesting times were found not to be statistically different ($p \leq 0.05$).

Averagely samples harvested late in the afternoon had the greatest amount of total carbohydrate (7.6 g/100 g) while those harvested early in the morning had the lowest carbohydrate content (6.1 g/100 g). French bean samples harvested at 3 pm and cooled after four hours had the highest carbohydrate content (8 g/100 g) while those harvested very early in the morning at 7 am and not cooled immediately or sooner had the least carbohydrate content 5.9 g/100 g and 5.8 g/100 g on wet weight basis.

Generally, for all the harvesting times and durations before start of cooling, fat content was found not to be significantly ($p \leq 0.05$).

Effect of harvest time and duration before cooling on salt, total minerals and fibre content of French bean

The effect of harvesting time and duration before cooling on salt, total minerals and fibre is presented in Table 3. Harvesting time and duration before cooling did not significantly affect the content of salt ($p>0.05$) in French beans, however, the results revealed significant differences ($p \leq 0.05$) in the ash and fibre content. On average, French bean samples harvested at 9 am recorded higher crude ash content compared to those harvested at 11 am.

Highest concentration of crude ash was found in French beans harvested at 9 am but cooled after 2 hours (1.87 g/100 g) while the lowest concentration of crude ash was recorded in samples harvested at 11 am and cooled after 4 hours and 6 hours (0.77 g/100 g). There were

Harvesting time	**Time to cooling***					
Moisture Content (%m/m)	0 hours	2 hours	4 hours	6 hours	8 hours	Mean
7 am	90.4^{ab}	90.3^{ab}	90.6^{ab}	90.2^{ab}	90.2^{ab}	90.3 ± 0.2^{a}
9 am	90.4^{ab}	91.1^{ab}	96.8^{a}	90.2^{ab}	90.8^{ab}	91.9 ± 3.2^{a}
11 am	87.2^{ab}	84.0^{b}	86.9^{ab}	84.1^{b}	88.9^{ab}	86.2 ± 7.2^{b}
1 pm	89.5^{ab}	88.7^{ab}	88.7^{ab}	88.8^{ab}	88.3^{ab}	88.8 ± 0.4^{b}
3 pm	89.9^{ab}	90.1^{ab}	89.3^{ab}	90.2^{ab}	90.3^{ab}	90.0 ± 07^{ab}
Mean	89.5	88.8	90.5	88.7	89.7	89.4
LSD (0.05)	6.4	6.4	6.4	6.4	6.4	2.8
CV (%)	4.3	4.3	4.3	4.3	4.3	4.3
Dry Matter (%m/m)						
7 am	10.3^{a}	9.8^{ab}	9.4^{c}	9.9^{ab}	9.8^{b}	9.8 ± 0.4^{b}
9 am	8.6^{b}	9.8^{ab}	9.0^{c}	9.1^{b}	8.9^{b}	9.1 ± 0.8^{c}
11 am	9.8^{b}	9.0^{b}	10.4^{b}	9.7^{ab}	11.1^{a}	10.0 ± 0.9^{b}
1 pm	10.3^{a}	11.6^{a}	10.6^{b}	10.6^{a}	11.7^{a}	11.0 ± 0.6^{a}
3 pm	10.7^{a}	10.3^{a}	12.2^{a}	10.5^{a}	11.3^{a}	11.0 ± 1.0^{a}
Mean	10.0	10.1	10.3	10.0	10.6	10.2
LSD (0.05)	1.03	1.03	1.03	1.03	1.03	0.23
CV (%)	6.2	6.2	6.2	6.2	6.2	6.2
Gross Energy (Kcal/100 g)						
7 am	29.3^{b}	28.7^{bc}	35.3^{b}	32.3^{b}	40.3^{a}	33.2 ± 4.1^{b}
9 am	37.0^{a}	42.4^{a}	42.3^{a}	41.4^{a}	42.9^{a}	41.2 ± 2.1^{a}
11 am	38.7^{a}	39.0^{a}	43.3^{a}	39.0^{a}	40.0^{a}	40.0 ± 5.9^{a}
1 pm	37.0^{a}	33.0^{b}	34.3^{b}	38.3^{a}	36.0^{b}	35.7 ± 2.3^{b}
3 pm	34.7^{a}	37.0^{ab}	33.0^{b}	33.7^{b}	32.3^{b}	34.1 ± 2.2^{b}
Mean	35.3	36.0	37.6	36.9	38.3	36.8
LSD (0.05)	4.9	4.9	4.9	4.9	4.9	2.2
CV (%)	8.2	8.2	8.2	8.2	8.2	8.2

*Means within column followed by different letters are significantly different based on Fishers Protected LSD test ($p \leq 0.05$).

Table 1: Effects of different harvesting times and duration before cooling on the physicochemical par ameters of French beans.

Harvesting time	Time to cooling*					
Protein Content (g/100 g)	0 hours	2 hours	4 hours	6 hours	8 hours	Mean
7 am	2.3^{a}	2.3^{ab}	2.3^{a}	2.2^{ab}	2.3^{ab}	2.2 ± 0.04^{a}
9 am	2.6^{a}	1.8^{ab}	2.5^{a}	1.9^{ab}	2.3^{ab}	2.2 ± 0.6^{a}
11 am	2.5^{a}	1.9^{ab}	1.8^{ab}	2.5^{a}	1.8^{ab}	2.1 ± 0.5^{ab}
1 pm	2.3^{a}	2.4^{a}	2.4^{a}	2.3^{a}	2.6^{a}	2.4 ± 0.1^{a}
3 pm	2.3^{a}	2.4^{a}	2.5^{a}	2.4^{a}	2.4^{a}	2.4 ± 0.1^{a}
Mean	2.4	2.2	2.3	2.2	2.3	2.3
LSD (0.05)	0.6	0.6	0.6	0.6	0.6	0.3
CV (%)	16.8	16.8	16.8	16.8	16.8	16.8
Fat content (g/100 g)						
7 am	0.14^{a}	0.12^{a}	0.14^{a}	0.12^{a}	0.16^{a}	0.14 ± 0.02^{a}
9 am	0.14^{a}	0.15^{a}	0.18^{a}	0.14^{a}	0.14^{a}	0.15 ± 0.03^{a}
11 am	0.14^{a}	0.14^{a}	0.15^{a}	0.14^{a}	0.16^{a}	0.15 ± 0.02^{a}
1 pm	0.14^{a}	0.14^{a}	0.14^{a}	0.14^{a}	0.14^{a}	0.14 ± 0.01^{a}
3 pm	0.14^{a}	0.16^{a}	0.15^{a}	0.13^{a}	0.16^{a}	0.15 ± 0.02^{a}
Mean	0.1	0.1	0.2	0.1	0.2	0.1
LSD (0.05)	NS	NS	NS	NS	NS	NS
CV (%)	9.7	9.7	9.7	9.7	9.7	9.7
Total carbohydrate(g/100 g)						
7 am	5.9^{a}	5.8^{b}	6.0^{a}	6.9^{a}	6.0^{ab}	6.1 ± 1.2^{ab}
9 am	5.9^{a}	6.9^{ab}	5.8^{a}	6.6^{a}	6.7^{a}	6.4 ± 0.6^{a}
11 am	5.9^{a}	6.2^{ab}	7.0^{ab}	6.8^{a}	7.8^{a}	6.7 ± 0.9^{a}
1 pm	6.7^{a}	7.8^{a}	7.7^{a}	7.7^{a}	7.9^{a}	7.6 ± 0.5^{a}
3 pm	6.9^{a}	7.3^{ab}	8.1^{a}	7.0^{a}	7.4^{a}	7.3 ± 0.8^{a}
Mean	6.3	6.8	6.9	7.0	7.2	6.8
LSD (0.05)	1.3	1.3	1.3	1.3	1.3	0.59
CV (%)	11.8	11.8	11.8	11.8	11.8	11.8

*Means within column followed by different letters are significantly different based on Fishers Protected LSD test (P ≤ 0.05).

Table 2: Effects of different harvesting times and duration before cooling on physic-chemical par ameters of French beans.

Harvesting time	Time to cooling*					Mean
Salt	0 hours	2 hours	4 hours	6 hours	8 hours	
7 am	0.07^{ab}	0.07^{ab}	0.06^{ab}	0.07^{ab}	0.07^{ab}	0.07 ± 0.01^{a}
9 am	0.05^{b}	0.08^{a}	0.06^{ab}	0.07^{ab}	0.06^{ab}	0.06 ± 0.02^{a}
11 am	0.07^{ab}	0.08^{a}	0.07^{ab}	0.08^{ab}	0.06^{ab}	0.07 ± 0.01^{a}
1 pm	0.05^{ab}	0.05^{ab}	0.05^{ab}	0.08^{ab}	0.06^{ab}	0.06 ± 0.01^{a}
3 pm	0.07^{ab}	0.08^{a}	0.07^{ab}	0.08^{ab}	0.06^{ab}	0.07 ± 0.01^{a}
Mean	0.06	0.07	0.06	0.07	0.06	0.06
LSD (0.05)	0.016	0.016	0.016	0.016	0.016	0.01
CV (%)	14.5	14.5	14.5	14.5	14.5	14.5
Crude Ash Content						
7 am	1.02^{a}	0.99^{a}	1.03^{a}	1.1^{a}	1.3^{a}	1.09 ± 0.1^{b}
9 am	1.35^{a}	1.87^{a}	1.41^{a}	1.34^{a}	1.8^{a}	1.55 ± 0.8^{a}
11 am	0.79^{a}	1.13^{a}	0.77^{a}	0.77^{a}	0.94^{a}	0.88 ± 0.4^{c}
1 pm	1.18^{a}	1.17^{a}	1.14^{a}	1.17^{a}	1.02^{a}	1.14 ± 0.1^{b}
3 pm	1.13^{a}	1.14^{a}	1.19^{a}	1.13^{a}	1.17^{a}	1.15 ± 0.03^{b}
Mean	1.09	1.26	1.11	1.1	1.25	1.16
LSD (0.05)	0.6	0.6	0.6	0.6	0.6	0.31
CV (%)	36	36	36	36	36	36.0
Crude fibre content						
7 am	0.92^{a}	0.93^{a}	0.85^{a}	1.00^{a}	0.77^{a}	0.89 ± 0.08^{ab}
9 am	0.92^{a}	0.85^{a}	0.94^{a}	0.93^{a}	0.94^{a}	0.92 ± 0.05^{a}
11 am	0.95^{a}	0.89^{a}	1.2^{a}	1.16^{a}	0.92^{a}	1.02 ± 0.30^{a}
1 pm	0.93^{a}	0.92^{a}	0.75^{a}	0.94^{a}	0.92^{a}	0.89 ± 0.07^{ab}
3 pm	0.87^{a}	0.91^{a}	0.89^{a}	0.85^{a}	0.86^{a}	0.88 ± 0.07^{ab}
Mean	0.92	0.9	0.93	0.98	0.88	0.922
LSD (0.05)	0.2	0.2	0.2	0.2	0.2	0.123
CV (%)	18.2	18.2	18.2	18.2	18.2	18.2

*Means within column followed by different letters are significantly different based on Fishers Protected LSD test (P ≤ 0.05).

Table 3: Effects of different harvesting time and duration before cooling on Crude ash content, crude fibre content, and salt content of French beans.

significant differences in crude fibre content ($p \leq 0.05$). The highest content of fibre was observed in samples harvested at 11 am (1.20% m/m) and cooled after 4 hours while samples harvested at 1 pm and cooled after 4 hours had the lowest fibre content (0.75% m/m) .

On average, bean samples harvested mid-morning (9 am and 11 am) had significantly higher crude fibre content compared to those harvested early morning (7 am) and later afternoon (1 pm and 3 pm).

Effect of harvesting time and duration before cooling on overall weight change of French beans

There were significant effect of delayed harvesting and delayed cooling on change in weight of French beans ($p \leq 0.05$). Each delay in harvesting and start of cooling resulted in reduced weight of French beans (Table 4). French bean samples cooled immediately after harvesting experienced the least weight loss (0.51%) while French bean samples cooled after eight hours resulted in highest weight loss (3%). There were significant differences in change in weight due to harvesting time and duration before cooling ($p \leq 0.05$).

Effect of harvesting time and duration before cooling on product and ambient temperature of French beans

The effect of harvest time and duration to cooling on the product temperature and its relation to ambient temperature is presented in Table 5. There was significant difference on the ambient temperatures and product temperatures with change in time of harvest and duration to cooling.

The highest ambient temperature for the day was recorded at 11 am (30.7°C). The lowest ambient temperature was recorded at 7 am (17.3°C). The lowest product temperature was recorded at 7 am (13.7°C), while the highest product temperature was recorded at 11 am (27.1°C)

For every increase in ambient temperature, there was increase in product temperature at harvest, an indication that the lower ambient temperature is more ideal for French bean harvesting.

Time Before cooling	Harvesting time*					Change in weight (%)
	7 am	9 am	11 am	1 pm	3 pm	
0 hours	994.8^{a}	995.0^{a}	997.9^{a}	993.1^{a}	993.7^{a}	0.51^{c}
2 hours	984.6^{ab}	986.3^{ab}	972.9^{b}	982.9^{a}	992.6^{a}	1.6^{bc}
4 hours	966.9^{b}	983.0^{ab}	971.8^{b}	984.9^{a}	984.2^{a}	1.9^{ab}
6 hours	945.9^{c}	972.3^{b}	964.3^{b}	978.6^{b}	989.7^{a}	2.2^{ab}
8 hours	968.7^{b}	973.0^{b}	982.6^{a}	990.2^{a}	988.2^{a}	2.9^{a}
Mean	972.2	981.9	977.9	985.9	989.7	1.9
LSD (0.05)	19.8	19.8	19.8	19.8	19.8	1.9
CV (%)	2.2	2.2	2.2	2.2	2.2	115.0

*Means within column followed by different letters are significantly different based on Fishers Protected LSD test ($p \leq 0.05$).

Table 4: Effects of harvest time and duration before cooling on the average percent change in weight of French beans.

Harvesting time	ambient temperature (°C)*	Product temperature (°C)*
7 am	17.3 ± 1.5^{c}	13.7 ± 1.1^{c}
9 am	24.0 ± 1.0^{b}	22.8 ± 1.0^{b}
11 am	30.7 ± 1.5^{a}	27.1 ± 1.4^{a}
1 pm	29.0 ± 1.0^{a}	24.7 ± 1.5^{ab}
3 pm	24.6 ± 1.0^{b}	22.8 ± 1.0^{b}
Mean	25.1	22.2
LSD (0.05)	2.14	1.8
CV (%)	4.5	4.2

*Means within column followed by different letters are significantly different based on Fishers Protected LSD test ($P \leq 0.05$).

Table 5: Mean ambient and product temperature of French beans harvested at different times.

Discussion

Harvest of vegetables results in reduced firmness due to loss of water, and as a result the produce may become increasingly susceptible to mechanical injury [7]. The levels of humidity, dry matter, carbohydrates, crude fiber, proteins, ashes, and energy value of the French beans were marginally affected by delay in cooling. French beans cooled immediately and within the first two hours exhibited little change in terms of moisture loss, weight loss, gross energy and change in and nutritional contents. A four hour delay and above resulted in an expected pattern of increased moisture loss and loss of weight. The moisture content of any food is an index of its water activity which is important as a measure of stability and susceptibility of the produce to microbial contamination. A short delay in cooling of French beans resulted in marked decline in crude nutritional contents of French beans.

Salts content of French beans was neither affected by time of harvest nor duration before cooling.

Weight losses of French beans increased considerably with increase in duration before cooling and delay in start of harvesting period. The rate of weight loss was, however, more important in long duration before cooling and late harvesting. According to Yagiz et al., green beans are considered unacceptable for sale after weight loss of more than 5% as a result of loss of moisture, wilting appearance, and loss of commodity value. Vegetables once harvested continue life processes therefore within hours of harvest crops can suffer irreversible losses in quality [7,1]. The rate of transpiration resulting into weight loss can be reduced by increasing the relative humidity, lowering the air temperature, minimizing the difference between air and product temperature and by reducing air movement. Changes in moisture content due to weight loss occur during storage but these depend on relative humidity in the store [8]. Appropriate temperature management between harvesting and marketing is the most effective way to maintain product quality [9]. Keeping vegetables harvested at low temperatures of about 20°C slows down the metabolic activity therefore; a delay of even one hour will lead to one day loss of shelf life [10,11]. Respiration and metabolic process within which the crop was harvested are related to temperatures of the ambient environment [12]. Low temperature storage conditions can quality attributes of vegetables such as texture, nutrition, and flavor [9].

The nutritional quality of French beans was marginally affected by the harvesting time and duration before cooling. The protein content of beans cooled immediately and those cooled after some time was found to be similar however, the slight variations observed were statistically insignificant ($P \leq 0.05$). This agrees with the findings of [13]. The protein content of different French beans may be explained by the degradation of proteins into small peptides and amino acids due to the metabolic processes [14]. The minor changes in protein content within the samples can be accredited to loss of water soluble nitrogen containing compounds. Protein contents in raw vegetables are usually low but have high biological value. The loss of moisture results in

increased protein content again addition of water during extraction may result in reduced levels of protein in vegetable samples. USDA [15] reported an increase in protein content of vegetables after drying when compared to fresh vegetables which was due to the presence of microbes in the samples. In general, average protein content was found to be higher in samples harvested late in the afternoon; this could be attributed to results from photosynthesis process in the mid-morning hours. In as much as carbohydrate content did not significantly different for various harvest time, there is slightly higher carbohydrate content for beans harvested later in the afternoon. The increase in slight increase of carbohydrates in the late afternoon can be attributed to release of carbohydrates due to declining photosynthetic activity in the late afternoon.

Delay in harvest and start of cooling resulted in reductions in crude fibre content.

The lowest crude fibre content was recorded for French bean samples harvested in the morning while samples harvested late in the afternoon had the highest crude fibre content. The difference in crude fibre content may be due to soil nutrient status and the age at which the beans were harvested [16].

The French beans samples harvested in the afternoon and cooled after six hours had the highest ash contents that ranged from 0.8 to 1.02 g/100 g. Fibre from vegetables serves the function of lowering blood cholesterol, weight control. Fat and salt contents in these samples were not significantly affected by the harvest time and duration to cooling. There were no remarkable differences in crude fat content in French bean; although the fat content remained unchanged it showed slight decrease when there was extended delay in start of cooling. This can be attributed to the fact that fats are rich in unsaturated fatty acids which is susceptible to oxidation [17]. According to Zang et al., immediate cold storage can reduce loss of fats in comparison to delay in start of cooling. No notable changes were realized in ash values with regards to time of harvesting and duration before cooling. This shows that ash content was not affected by time of harvesting and duration before cooling. Delay in harvesting with increase in time interval from harvesting to cooling resulted in loss of weight of various French bean samples. The reduction in weight with each delay in harvesting was due to longer increased temperature that enhanced moisture loss. Each delay in harvesting [18].

On average, protein content was in line with the overall market expectation, at 2.3 g/100 g against market expectation of 2.10 g/100 g. Carbohydrate content was equally very high at 6.8/100 g against retail market expectation at 3.10 g/100 g. Crude fibre content was however very much below market expectation, at 0.922 g/100 g against market expectation of 3.4 g/100 g. Fat content was equally lower than market expectation at 0.1 g/100 g against market expectation of 0.4 g/100 g.

Conclusion

Harvesting time and duration to start of cooling have a significant effect on the shelf life and overall quality of French beans. In general, the longer the duration to cooling and late harvesting time, the faster the deterioration of the French bean pods. French beans harvested in the afternoon have higher weight loss, but with increased protein, carbohydrate and ash content. Quality and improved shelf life of French beans starts immediately after harvesting. It is therefore important for farmers to harvest French beans early in the morning and cool them as soon as possible for improved quality.

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