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Pitout JDD, Church DL, Gregson DB, Chow BL, McCracken M, Mulvey M, Laupland KB (2007). Molecular epidemiology of CTXM-producing Escherichia coli in the Calgary Health Region: emergence of CTX-M-15-producing isolates. Antimicrob. Agents Chemother. 51: 1281-1286.

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Full Length Research Paper

The design and testing of an indirect cabinet solar dryer, for thin layer drying of *Rastrineobola argentea* fish, under the climatic conditions of Maseno, Kenya

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In spite of the high global demand for fish which is a major source of animal protein, nearly 10% (13 million tons) of the world's total fish production is lost through spoilage due to inadequate cold storage and poor marketing/distribution channels. Fish is a highly perishable product that is processed by freezing, canning, salting and drying. About 40% of fish landings in developing countries are preserved through traditional processing methods (smoking, drying and salting) organized at artisanal level. As a result of increased trade and co-operation among neighboring African countries over the past years, processed products from the artisanal sector now form a significant part of the small pelagic fish products traded intra-regionally. Lake Victoria provides about 95% of the total fish landings in Kenya, with *Rasrineobola argentea* (one of the pelagic species) being the second commercially important fish. It is harvested in very large quantities and is readily available at affordable price and widely used for both domestic and industrial purposes. Open-sun drying is the main preservation method employed by the fish farmers and involves spreading the fish on open ground where it is exposed to contamination, infestation and adverse weather conditions. It is estimated that post harvest losses of between 20 and 50% occur especially during rainy seasons. Although, the landings of *R. argentea* are higher as compared to other fish species, the value of the catch is often very low due to these huge losses. In an effort to curb these losses, a model of an indirect forced convection solar dryer was developed and tested for thin layer drying of *R. argentea* fish. The fish, in 10 kg batches were loaded onto the dryer and the moisture content reduced from an initial value of 73% (w. b.) to between 16 and 20% (w. b.) after 11 h of drying at average air flow rate of 0.017 kg/s, where open sun drying took 18 h. The mean efficiencies of collector and drying systems were 9.36 ± 3.95% and 11%, respectively. The drying rate constants of the fish in dryer were found to be: 0.146, 0.206 and 0.148 for the fish in the top, middle and bottom trays, respectively.

Key words: Twin collector, indirect, forced convection, cabinet solar dryer, *Rastrineobola argentea* fish.

INTRODUCTION

The food shortage in developing countries is partly due to inadequate preservation of food products so as to cater for long term needs (Madhlopa et al., 2002). When properly dried, food products have longer shelf life, better marketability and maintain a steady price. Open sun drying is the simplest and cheapest preservation option, for small scale farmers in developing countries who cannot afford artificial dryers. It involves laying the

products bare on the ground where it is exposed to contamination and attack by bacteria, infestation by insects, birds, animals and rodents (Madhlopa et al., 2002). It is also laborious as the food layers have to be turned over and over again periodically to ensure uniform drying. The food may even lose some of the more fragile vitamins because of being exposed directly to sunlight. Furthermore, there are no mechanisms for controlling the drying process which is heavily dependent on weather conditions (Alamu et al., 2010). Thus, the use of open sun drying method in the preservation of agricultural and marine food products is partly responsible for the huge post harvest losses of 30 to 40%, encountered by farmers in developing countries (Azhrarul and Hawlader, 2010).

Given the tropics and subtropics have a abundant solar energy resource potential, as confirmed by the numerous studies that have been conducted in these regions, the use of solar technologies (solar dryers) in the drying of fruits, vegetables, cereals legumes, spices, fish and meat has been shown to be promising (EPZ, 2005). They are a better option since the drying of the food product takes place in an enclosed and protected unit, under controlled conditions of temperature and air flow, where the quality of the final dried product and rate of drying can be controlled (Gunasekarau et al., 2012). Solar dryers produce a better quality in the final dried product than open sun drying (Eventurk and Eventurk, 2007) and are classified as either active or passive depending on the mode of application of the solar energy. Active dryers have forced air circulation while passive models make use of air buoyancy caused by temperature and pressure gradients. Although passive dryers are cheap to implement and have no electrical or mechanical components, the air flows generated are not sufficient to penetrate bulk products (Buchinger and Weiss, 2002).

In general, active dryers (forced convection) have higher reliability and efficiency since they maintain continuous flow although their use is limited by the requirement of electricity needed to operate the electrical and mechanical components. They are more suitable for drying high moisture content products such as fruits, vegetables bananas and marine products (Jayaraman et al., 2000). Natural convection dryers typically exhibit lower overall drying efficiencies, (10 – 15%) than forced convection models (20 - 30%) (Buchinger and Weiss, 2002).

Solar dryers are further grouped as direct or indirect depending on whether or not the product is exposed to direct solar radiation. For direct solar dryers, the product is held in an insulated unit with a transparent plastic or glass cover which allows air flow through small holes at the top and bottom. Heat generated by the solar radiation Is absorbed by both the surfaces of the product and dryer is transferred to the air inside the collector which then flows over the product laid on perforated trays and causes drying (Buchinger and Weiss, 2002). The main disadvantage of these dryers is the direct exposure of the product to sunlight which affects essential components often resulting in discoloration, vitamin loss and overheating in the thin top layer of the product (Sreekumar et al., 2008).

In contrast, indirect dryers consist of two separate units; solar collection and drying chamber such that the product is not exposed to direct solar radiation. The interior surfaces of the solar collector absorb radiation and the heat generated increases the temperature of the surrounding air. The heated air is either forced or flows by natural convection through the drying trays. As the moist air exits through vents located at the top of the dryer, a reduction in the internal pressure is created within the cabinet and ensures the continual drawing of ambient air into the dryer.

In the design process of a solar dryer, the physical and thermal properties of the product; moisture diffusion, heat and mass transfer, specific energy consumption, activation energy, their dependence on the input air velocity and temperature have to be taken into account. The efficiency of a solar dryer depends on the ambient air temperature, air flow speed, relative humidity, quantity, thickness and moisture content of the product to be dried and the intensity of the incident solar radiation. Thin layer drying models are used to predict drying times and generalize kinetics of the drying processes of food/agricultural products. Since the kinetics of drying depends on ambient temperature, air velocity and material characteristics (Doymaz and Pala, 2002) the prediction of drying time is crucial to increasing dryer capacity and the reduction of energy consumption (Ismail and Wootton, 1992).

Fish is a major source of animal protein and an important food item in many countries. It is highly perishable and can be preserved by proper refrigeration or drying although dried fisheries are more popular because their special taste and flavor. The frequency of intake of small fish is between 50 and 80%, of all the fisheries eaten in many developing countries (Bala and Mondol, 2001). In Kenyan context, the fishing industry has in the last two decades evolved from a domestic consumption oriented to an export industry with value addition processing being applied (Nyeko, 2008). The sector provides live-hood, income and employment to more than 2 million people, with Lake Victoria providing 95% of the total fish landed (Odongokara, 2008). It has thus been identified in the country's vision 2030, as one of the sectors that if improved could effectively contribute

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to the improvement of food security (Nyeko, 2008). The fishing is mostly carried out by artisan fishermen operating small boats in inland lakes and marine waters. Some of the harvested fish is sold fresh while a significant portion is processed for later consumption. The main fish landed in Lake Victoria include: *Rastrineobola argentea*/Dagaa (62.9%) Nile perch/*Lates niloticus* (29.9%), Tilapia/*Oreochromis niloticus* (5.3%) *Halplochromines*/Fulu (1%) and others (0.8%) (Ofulla et al., 2007). The poor infrastructure systems coupled with the lack of adequate cold storage and distribution facilities, has made the artisan fish farmers to resort to indigenous fish preservation methods such as smoking, salting and open sun drying. But open sun drying is the most prevalent method and involves the laying of fish bare on the ground or on raised racks. This method exposes the fish to infestation by insects, bacterial attack and contamination; moreover the drying process is very slow (lasts about one week) and depends on the climatic conditions and spoilage often occurs. On the whole, the physical and organoleptic qualities of most traditional sun dried fish products available in the market are not satisfactory for human consumption, and as such a large proportion of these fisheries are being utilized for production of animal feed and fishmeal (EPZ, 2005). Although the landings of *Rastrineobola.* argentea are higher compared to other fish species, the value of the catch is often very low due to losses (Owaga et al., 2011) and the use of these methods is one of the major causes of the huge economic and quality post harvest losses estimated at between 20 and 50% during rainy seasons, currently incurred by the fish farmers (Owaga et al., 2011).

As a result of the perceived role of the fisheries sector in the improvement of the country's food security, more hygienic processing practices need to be established that can enhance the economic and nutritional value of the fisheries and extend their shelf life. Already there is a threat of export ban on fish products from developing countries by the EU market and hence the urgent need to assess the technical feasibilities of improved drying methods such as drying racks and solar dryers (Mohamed et al., 2005). Very few studies have been reported on the use of solar dryers for the fish in Lake Victoria, in particular only one study has been reported on the investigation of the drying characteristics and quality attributes of *Rastrineobola. argentea* and *Stolephorus delicatulus* fish species, under the climatic conditions of coastal Kenya (Oduor-Odote et al., 2010), although a relevant study its findings are not directly useful to the development of a large-scale solar dryer for the prevailing climatic conditions around Lake Victoria due to the variations in the metrological factors in the two sites. The present work thus provides useful information on the drying characteristics of *Rastrineobola argentea* fish under the prevailing climate conditions of the relevant region and therefore forms part of the required data useful for the development of appropriate solar drying technologies for this particular fish product. Moreover, the results which have been obtained in this study are similar to what other studies have obtained (Oduor-Odote et al., 2010).

Description of the solar dryer

The indirect cabinet solar dryer was designed for the climatic conditions of Maseno, the materials used in the construction were: well-seasoned cedar timber, G.I sheets, transparent glass (5 mm thickness), white polythene sheets, PVC waste pipes (diameter 8.5 cm), electric fan and a 50-W solar PV module. The drying system consists of two solar air heaters with a total glazing area of 5.0 m^2 made from wooden frames and transparent glass (5mm thickness), the collectors were connected to the drying chamber using plastic waste pipes. The drying chamber consists of 20 trays made of wooden frames and aluminum gauzing, spaced 0.20 m apart each with area 1 m^2, a 30 cm tall chimney, an electric car fan and a 50-W solar PV module (Figure 1).

Design parameters of the solar dryer

The design parameters of the solar dryer, some of which are specified in Table 1, were calculated from the mathematical relations defined below, (Onyinge et al., 2014)

1. The collector tilt γ for maximum incident solar radiation is usually taken as the latitude of the location, and is given by:

$$\gamma = 10^o + lat\varphi \quad (1)$$

where $lat\phi$ is the latitude of the site location (since $\phi = 0^o$, for Maseno, Kenya), in this case to allow rain off a value of $\gamma = 10^o$ was used.

2. The ratio of length to width of the air heater was taken as 1.5 and the length of the drying chamber L_s therefore given by:

$$L_s = \frac{A_{dc}}{w} \quad (2)$$

where A_{dc} and w are the area and width of the collector, respectively.

3. The aggregate thin drying layer thickness $h_L \leq 200mm$ was used.

4. The quantity of moisture to be removed m_w was obtained according to the relation:

Figure 1. Photographic view of the prototype indirect cabinet solar dryer designed and fabricated at Maseno University, Kenya.

$$m_w = w_w \frac{m_i - m_f}{1 - m_f} \quad (3)$$

Where, m_i initial moisture content, m_f is final moisture content, w_w is initial product mass.

5. The total volume of air needed to remove the moisture was obtained using the relation:

$$V_A = \frac{m_w L_t R_a T_a}{C_{pa} P_a (T_o - T_f)} \quad (4)$$

Where, R_a is specific gas constant, P_a the partial pressure of dry air in the atmosphere, C_{pa} the specific heat capacity of air at constant pressure, T_f the temperature of air leaving the drying chamber, T_a the ambient temperature, L_t the latent heat of vaporization of water.

6. The volume air flow rate was then obtained from the relation:

$$\dot{v} = \frac{V_A}{t} \quad (5)$$

Where, t is total time needed to dry a given sample of the product.

7. The chimney length was taken to be $1/15$ of the collector length

8. Thermal efficiency of the solar collectors was obtained according to the equation:

$$\eta_c = \frac{mC(T_o - T_i)}{A_c I} \times 100 \quad (6)$$

Where, m is air mass flow rate, C specific heat capacity of air, T_i collector inlet air temperature, T_o outlet air temperature, I incident solar radiation and A_c the collector area. A plot was then made of the thermal efficiency of collector against time.

9. The system drying efficiency for the solar dryer was calculated according to the equation:

Table 1. The theoretical parameters of the solar dryer.

Quantity	Description	Theoretical values
w_w	Mass of product to be dried	10.0 kg
m_i	Initial moisture content of product	73% (Oduor Odote et al., 2010)
m_f	Final moisture content of product	15%
t	Total time of drying	15 h
m_w	Mass of water evaporated	6.8 kg
V_a	Volume of air needed to evaporate moisture	1092.4 m^3
v	Volume air flow rate	0.0202 m^3 /s
η_c	Collector system efficiency	43.5%
η_d	Drying efficiency	11.4%
R_a	Specific gas constant	287.1 J/kg K
P_a	Partial pressure of air in atmosphere	101 KPa
C_{pa}	Specific heat capacity of air	1007 J/kg K
L_t	Latent heat of vaporization of water	2260 KJ/ K
T_f	Temperature of air leaving dryer	301.5 K
T_o	Temperature of leaving collector	343 K
T_a	Ambient air temperature	298 K
I	Mean solar radiation incident on collectors	496 W/m^2
A_c	Total surface area of collectors	5.0 m^2
l_s	Length of chamber	2.1 m
w	Width of collector	1.2 m
l	Characteristic length	2.0 cm
P_f	Power used to operate fan	14.6 W

$$\eta_p = \frac{m_w L_t}{IA_c + P_f} \quad (7)$$

m_w is weight of water evaporated from the product, L_t is the latent heat of vaporization of water , P_f power used to drive the fan.

10. The effective moisture diffusivity was obtained from the drying rate constant according to the relation:

$$k = \frac{\pi^2 D_{ef}}{4l} \quad (8)$$

where l is the characteristic length of the product.

EXPERIMENTAL PROCEDURES

Measurement of moisture ratio/drying rates

The drying tests on *Rastrineobola argentea* fish were conducted using the indirect forced convection solar dryer under full load conditions, with the first batch being dried on 10th and 11th June 2014 while the second was dried on 24th and 25th June 2014, between 9:00 and 16:00 h. The performance of the dryer was evaluated for drying of 10 kg batches of *Rastrineobola argentea* fish with an initial moisture content of 73% (w. b.) (Oduor-Odote et al., 2010), loaded in thin layers on each of the trays. All the weight measurements were conducted using a digital balance model XL-6100, with measurement range: 0.0 to 6100 g and accuracy ± 0.1 g. The initial weights of the control fish samples in the top, middle and bottom trays were first recorded and thereafter the same samples were removed from the dryer and weighed at two-hourly intervals throughout the entire drying period. The drying was only stopped at the stage when there were no significant differences between three

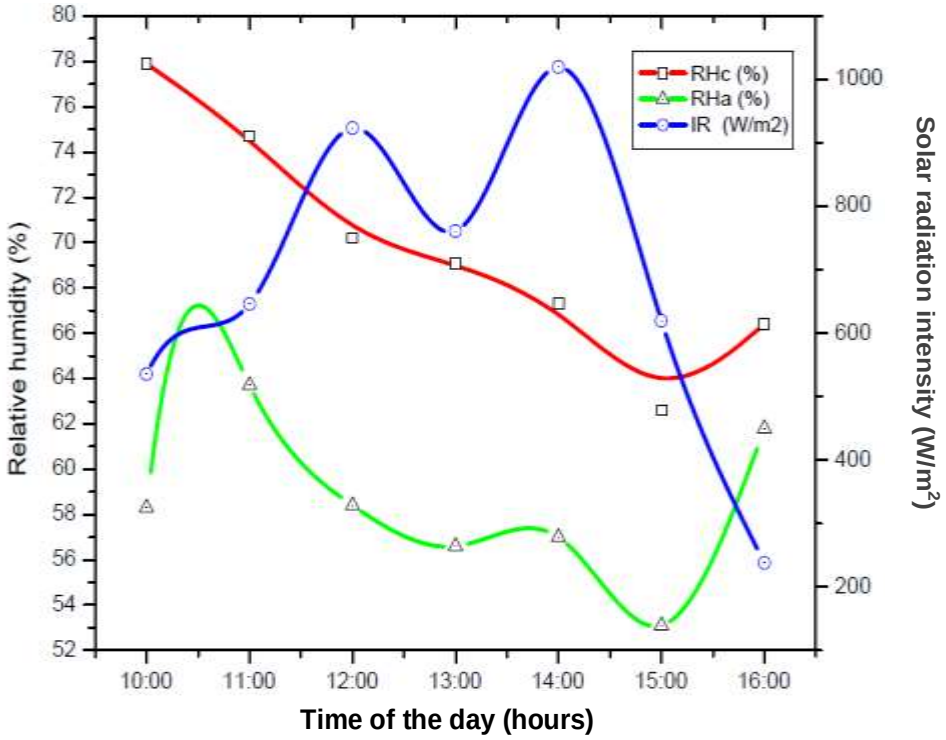

Figure 2. The variation of relative humidity of air inside and outside the chamber with the incident solar radiation on the first day of drying. R Hc: relative humidity of chamber air; R Ha: relative humidity of ambient air; IR: mean solar radiation intensity.

consecutive weights of the same sample. Simultaneous weight measurements were also recorded from open sun dried control samples during the same period to enable comparison of the drying rates.

Measurement of temperature

Temperatures readings were taken at intervals of 10 min for the ambient air and at various locations in the collectors and drying chamber using thermocouples connected to a data logging system, model 2286A, Company: Fluke, Country of manufacture: Everett WA, USA, consisting of type J (Iron - Constantan), K (Chromel - Alumel) and E (Chromel - Constantan) thermocouples with measurement ranges - 200 to 760°C, - 225 to 1350°C and - 250 to 1000°C, respectively.

Measurement of the incident solar radiation

The instantaneous incident solar radiation was measured at intervals of 1 min using a solariometer model SL 200, (Company: E-instruments, Country of manufacture: France), with measurement range of 1 to 1300 W/ m^2, accuracy ± 5 %, measurement frequency: 2 measurements per second.

Measurement of relative humidity

The relative humidity of air inside and outside the chamber was measured at hourly intervals using two digital Pyschrometer model 5105, (company: JENWAY, country of manufacture: UK). One placed inside the drying chamber and the other outside.

Measurement of air flow rates

The air speed and volume flow rates were measured at the collector outlets and chimney at hourly intervals using an anemometer; (VELOCICAL model 8357, Company: TSI, Country of manufacture: USA), with measuring ranges: 0.0424 to $1.170 \times 10^8 m^3/s$ for volume flow rates and accuracy ranges: ± 0.05 for 2.5 to 10 m/s, ± 0.025 m/s for 10 - 30 m/s and ± 0.5 for 30 to 50 m/s air velocities.

RESULTS AND DISCUSSION

Relative humidity of the air

The variation in the relative humidity of ambient and chamber air with time during the drying is presented in Figures 2 and 3. The mean relative humidity in the drying chamber on the first and second days of drying were 69.7 ± 4.78 and 52.7 ± 7.30%, respectively against corresponding ambient values of 58.5 ± 3.23 and 57.9 ± 3.52%, on the first and second days, respectively. There is a general decreasing trend in relative humidity of air with increasing solar radiation intensity, but the relative humidity in chamber is higher than for ambient air on the first day of drying while for second day, it is lower than that of ambient air. This observation is accounted for by the fact that on the first day, the fish is more moisture

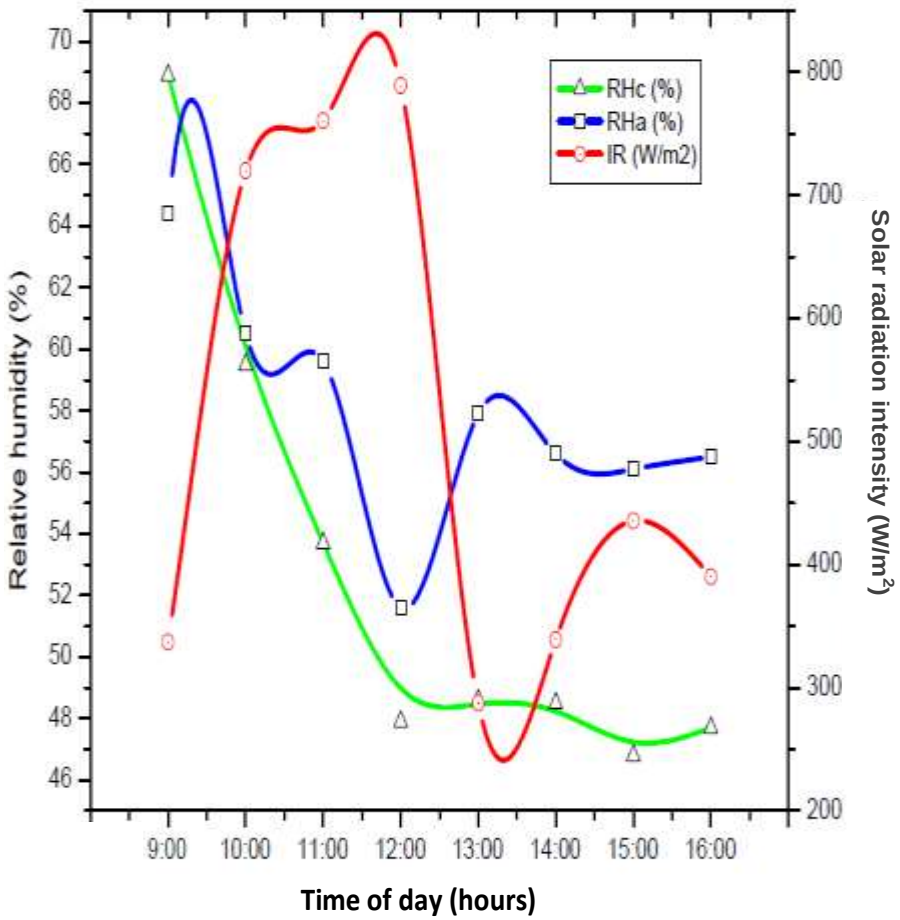

Figure 3. The variation of relative humidity of air inside and outside the chamber against the incident solar radiation on the first day of drying. R Hc: relative humidity of chamber air; R Ha: relative humidity of ambient air; IR: mean solar radiation intensity.

laden and so the humidity in the chamber is increased while on the second day, the fish is relatively drier and chamber humidity is lower.

Temperature

The temperature profiles for various locations in the drying system as well as the incident solar radiation at different times are presented in Figures 4 and 5. The mean solar radiation intensities were found to be 635.2 ± 250 W/ m^2 and 507.3 ± 197.9 W/ m^2 during the first and second day of drying respectively. It was found that the mean collector outlet temperatures were 43.6 ± 8.49 and 50.1 ± °C on the first and second day, respectively. The mean temperatures at the bottom, middle and top trays were found to be 25.9 ± 3.45, 25.1 ± 2.55 and 26.2 ± 3.54°C respectively on the first day and 28.2 ± 2.63, 27.2 ± 2.81 and 27.8 ± 3.12°C respectively on the second day. The mean temperatures at the bottom of the chamber and ambient air were found to be 31.2 ± 5.98 and 15.6 ± 2.99°C on the first day respectively and 32.8 ± 3.52°C and 27.2 + 1.84°C on the second day respectively. The temperature of the drying chamber is nearly constant and has a mean value of 31.2 ± 5.98°C and 32.8 ± 3.52°C on the first and second days of drying respectively while the mean ambient temperature was found to be 15.6 ± 2.99 and 27.2 ± 1.84°C on the first and second days of drying respectively.

There is a direct variation of temperature with solar radiation intensity for all the components of the drying system. The higher temperatures are observed at the collector system outlet as compared to other components. On all the drying days, the temperature of the bottom chamber is higher than that of the ambient air. It is also observed that the mean temperature of the bottom and top trays are higher than that of the middle trays. The fact that the mean temperature of the top trays is higher than the middle trays is accounted for by the absence of insulation on the dome of the dryer (made of un-insulated G. I. sheets), a unique design feature of this dryer, the dome therefore absorbs solar radiation and raises the temperature of the surrounding region. The

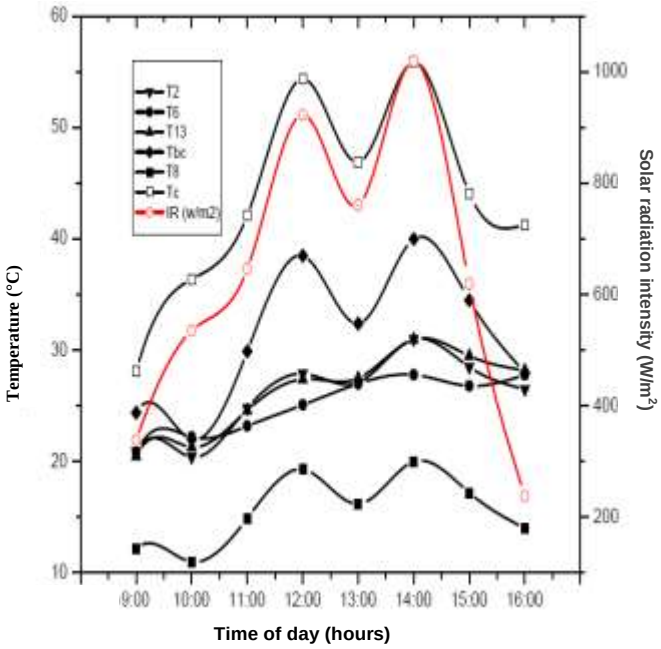

Figure 4. Variation of mean ambient, collector outlet and chamber temperatures with time for the first day of drying. IR: solar radiation intensity; T2: bottom tray temperature; T13: middle tray temperature; T6: top tray temperature; T bc: chamber bottom temperature; TC: collector outlet temperature; T8: ambient temperature.

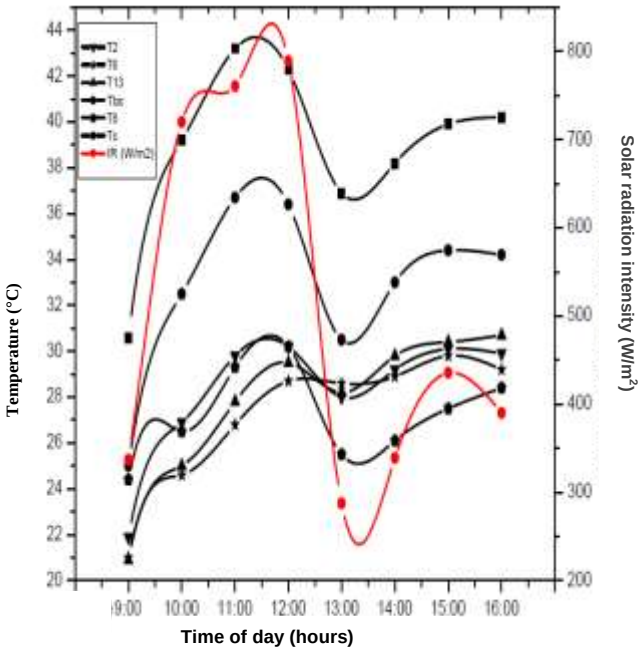

Figure 5. Variation of temperature of bottom, middle and top trays with time during the second day of drying. IR: solar radiation intensity; T2: bottom tray temperature; T13: middle tray temperature; T6: top tray temperature; T bc: chamber bottom temperature; TC: collector outlet temperature; T8: ambient temperature.

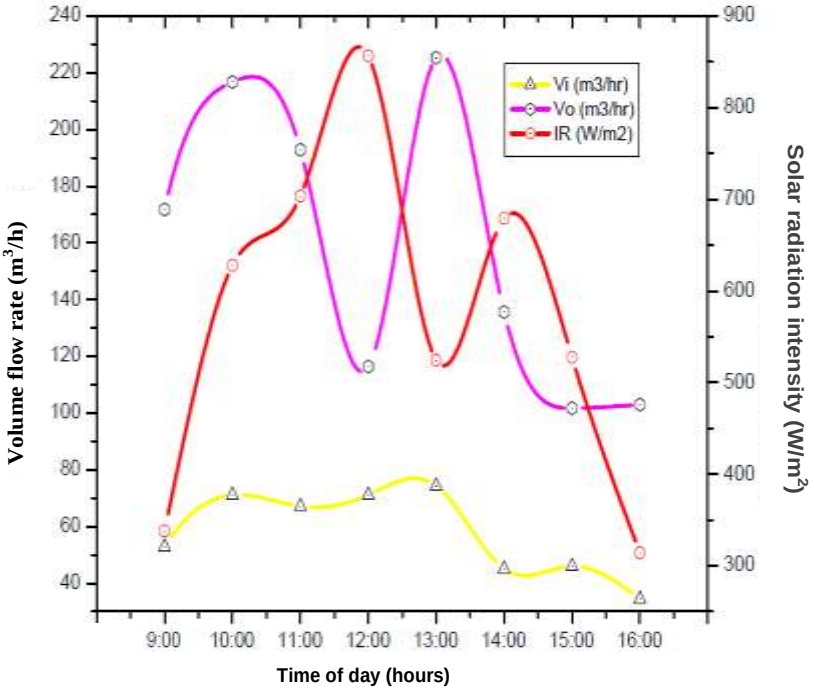

Figure 6. The variation of the mean in and outflow air volume flow rates with time during drying Vi: rate of air volume flow into dryer; Vo: rate of air volume flow out of dryer.

fact that the temperature of the bottom chamber is lower than that of the collector outlet suggests the existence of thermal losses along the air ducts.

Air flow rates

The variation of air volume flow rates with time in the solar dryer during the days of drying have been presented in Figure 6 below, from which it is observed that the total air volume flow rate from the collectors is nearly constant but there is a larger variation in the air volume flow rate out of the chimney. The average total air volume flow rate from the combination of collectors into the drying chamber was observed to be 0.0190 ± 0.0048 kg/s while the air flow rate out of the chimney was found to be 0.051 ± 0.0153 kg/s during the days of drying. The observed constant air volume flow rate from the collectors into the drying chamber is maintained by the exhaust fan incorporated within the dome of the dryer.

Moisture content

The moisture curves for *Rastrineobola argentea* fish presented in Figures 6 and 7, consists of falling and constant sections. The first (Figures 6) occurs at the initial stage of drying where the fish loses moisture more rapidly at almost constant rate while the next (Figure 7) occurs at later stages of drying where the rate of moisture loss decreases to almost zero. From Figure 6, it is observed that the moisture content of the fish in the solar dryer is reduced from 73 to 40, 29, 23, 42 and 31% (w. b.) for the middle trays, top right, top left bottom left, and bottom right trays respectively after the first 6 h on the first day and then to final values of: 8% (w. b.) for the middle right tray and bottom right trays, the bottom left and top right and middle right trays and 9% (w. b.) for the top left tray and 10% for the middle left tray after another 5 h on the second day (Figure 7). There is a greater loss in moisture for fish in the top trays as compared to other trays at the end of the first day, even though at the end of the second day of drying, there is no significant difference in the moisture ratio of fish with most of the fish in the various trays attaining moisture contents of less than 10%. The rapid loss in moisture of the fish at the beginning of drying is attributed to the increasing solar radiation intensity received at the collectors which raises the temperature of the inlet ambient air thus lower its relative humidity and increases its ability to absorb moisture from the fish in the solar dryer.

Drying rates

The variation of the drying rates with time for the two

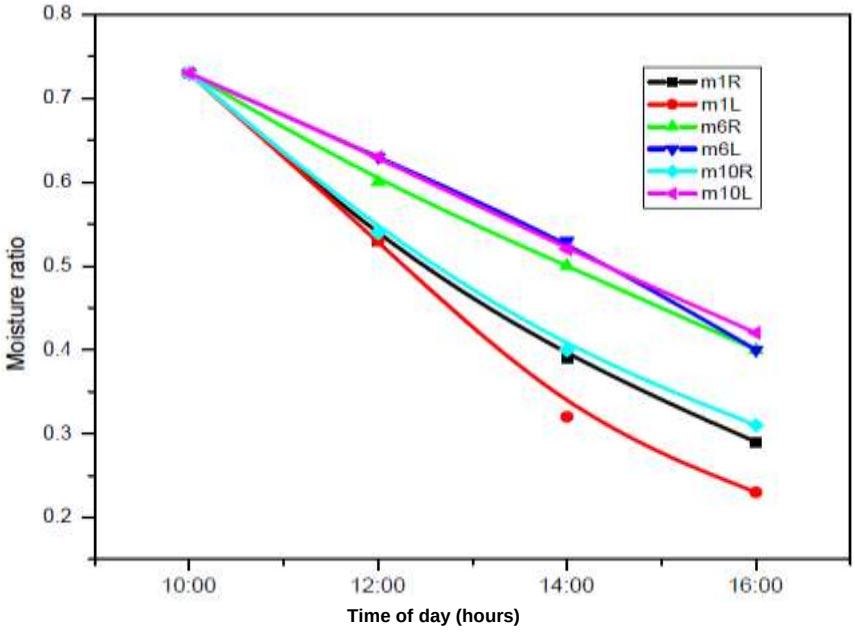

Figure 6. The variation of the mean moisture ratio of fish in the dryer with time on the first day of drying. m1R: mean moisture ratio of fish in the top right tray; m1L: mean moisture ratio of fish in the top left tray; m6R: mean moisture ratio of fish in the middle right tray; m6L: mean moisture ratio of fish in the middle left tray; m10R: mean moisture ratio of fish in the top right tray; m10L: mean moisture ratio of fish in the top left tray.

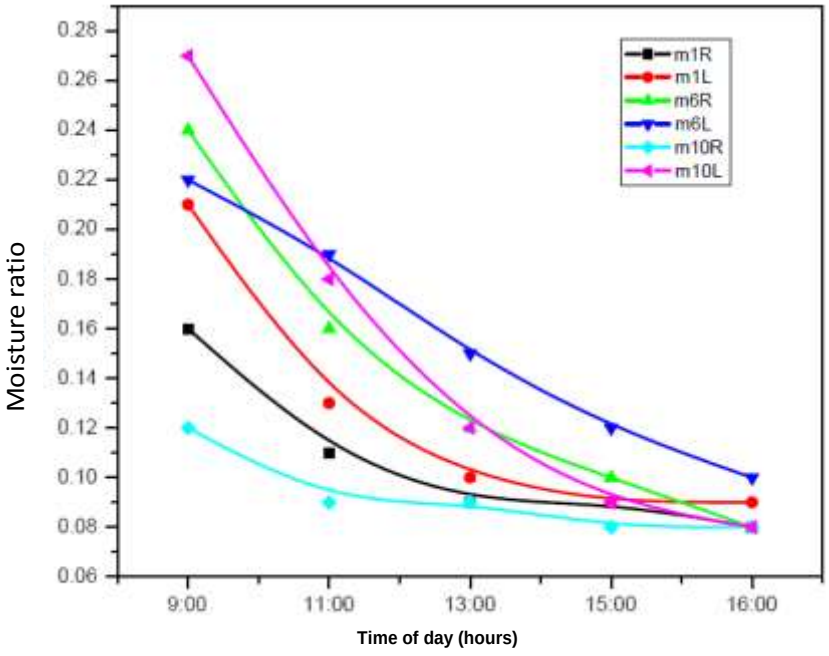

Figure 7. The variation of the mean moisture ratio of fish in the dryer with time on the second day of drying. m1R: mean moisture ratio of fish in the top right tray; m1L: mean moisture ratio of fish in the top left tray; m6R: mean moisture ratio of fish in the middle right tray; m6L: mean moisture ratio of fish in the middle left tray; m10R: mean moisture ratio of fish in the top right tray; m10L: mean moisture ratio of fish in the top left tray.

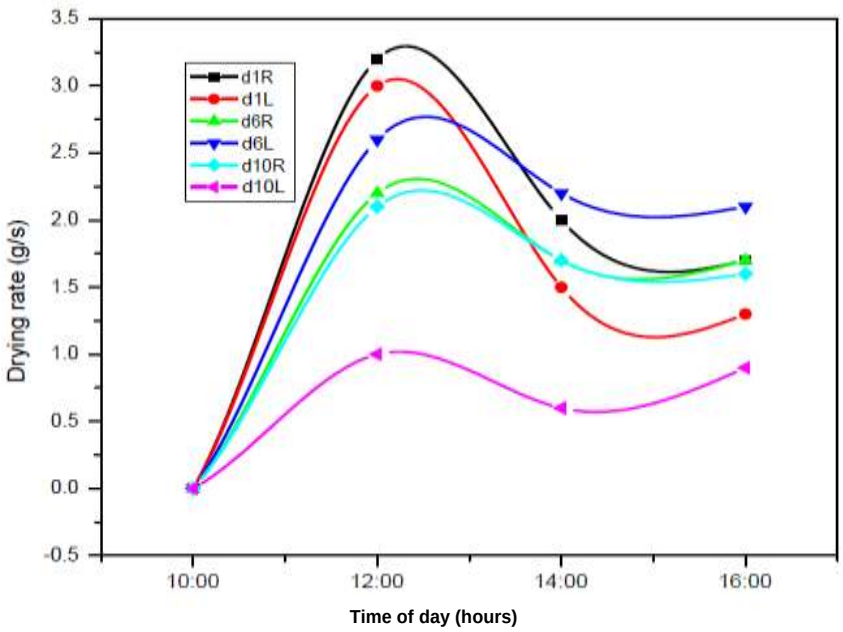

Figure 8. Variation of drying rates with time on the first day of drying. d1R: drying rate of top right tray; d1L: drying rate of top left tray; d6R: drying rate of middle right tray; d6L: drying rate of middle left tray; d10R: drying rate of bottom left tray; d10L: drying rate of bottom right tray.

days of drying are presented in Figures 8 and 9, from which it is observed that there is first an increase in the drying rates in the first two hours of drying, a slight drop in the next two hours and then finally almost constant rate at the end of the first drying day. On the second day, there is first a decreasing then an almost constant rate at the end of the second day when equilibrium moisture content of the fish is attained. The highest drying rates are observed in the top trays as compared to the other trays in the first four hours of drying. The drying rates of the fish are higher on the first day of drying because the (moisture content of the fish is higher) surface is saturated with moisture and the rate of evaporation of moisture from the fish surface rate which is controlled largely by external ambient parameters of temperature and air flow rate. The drying rate at later stages (second day) depends on the rate of the diffusion of moisture from the interior of the product to the surface rather than the external parameters as all the surface moisture has been removed. The moisture has to be diffused from the interior of the product to the surface first before being evaporated to the surrounding. The rate of diffusion decreases at lower concentration of moisture in the fish and hence the observed decrease in the drying rates on the second day.

Drying rate constant (*k*) **and effective moisture diffusivity (**D_{ef}*)*

The linear graphical plots obtained for the -In M. R. against time for the top, middle and bottom trays are presented in Figures 11 - 16. The drying constants were computed from the gradients of the graphs and obtained as follows: 0.146 ± 0.0146 hr^{-1} and 0.150 ± 0.0224 hr^{-1} for the bottom left and right trays, 0.135 ± 0.0077 hr^{-1} and 0.141 ± 0.0142 hr^{-1} for the middle left and right trays, and 0.141 + 0.0142 hr^{-1} and 0.151 + 0.0132 hr^{-1} for the top left and right trays. The effective moisture diffusivity values derived from the slope of In M. R. versus time plots according to Equation 8, were obtained as follows: $1.183 \times 10^{-3} m^2/s$, $1.119 \times 10^{-3} m^2/s$ and $1.183 \times 10^{-3} m^2/s$ for the top, middle and bottom trays, respectively. It is observed that the middle trays have a slightly lower value of moisture diffusivity as compared to the bottom and top trays. This observation can be explained by the fact that at the top and bottom trays the temperatures are higher than in the middle trays hence both the rate of moisture evaporation and diffusivity are higher which increases the rate of drying.

Thermal and drying efficiencies

The thermal efficiencies of the collectors were computed using Equation 5, and the variation of efficiency of the collector system and the instantaneous solar radiation intensities with time are presented in Figure 10. The efficiency of the collector system increases with the incident solar radiation and both peak at almost the same time of the day, between 11:30 and 13:30 h. The

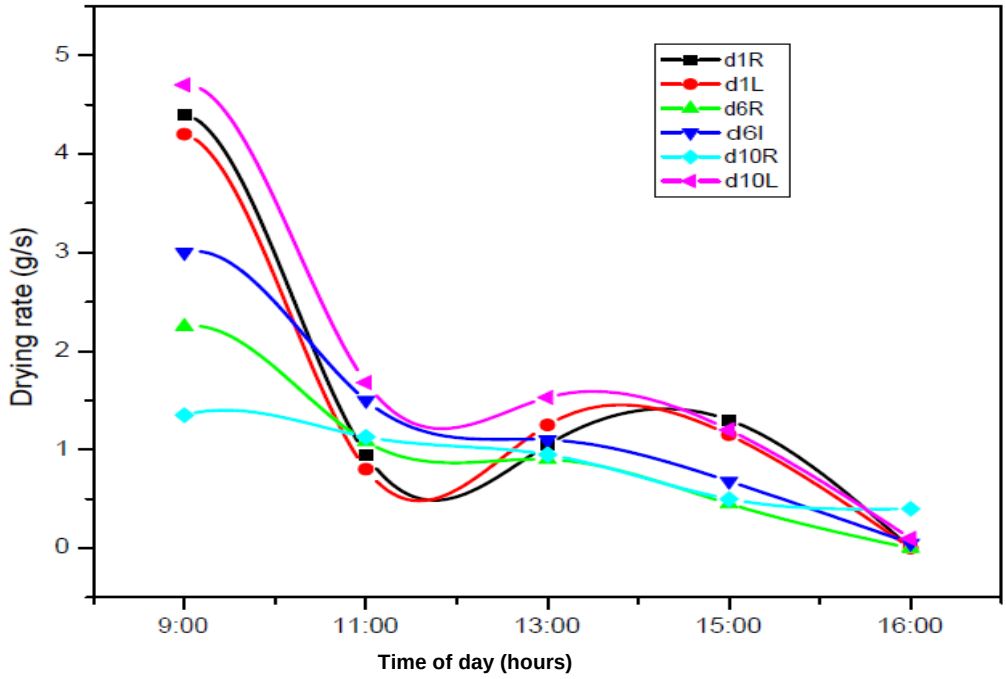

Figure 9. Variation of drying rates with time on the second day of drying. d1R: drying rate of top right tray; d1L: drying rate of top left tray; d6R: drying rate of middle right tray; d6L: drying rate of middle left tray; d10R: drying rate of bottom left tray; d10L: drying rate of bottom right tray.

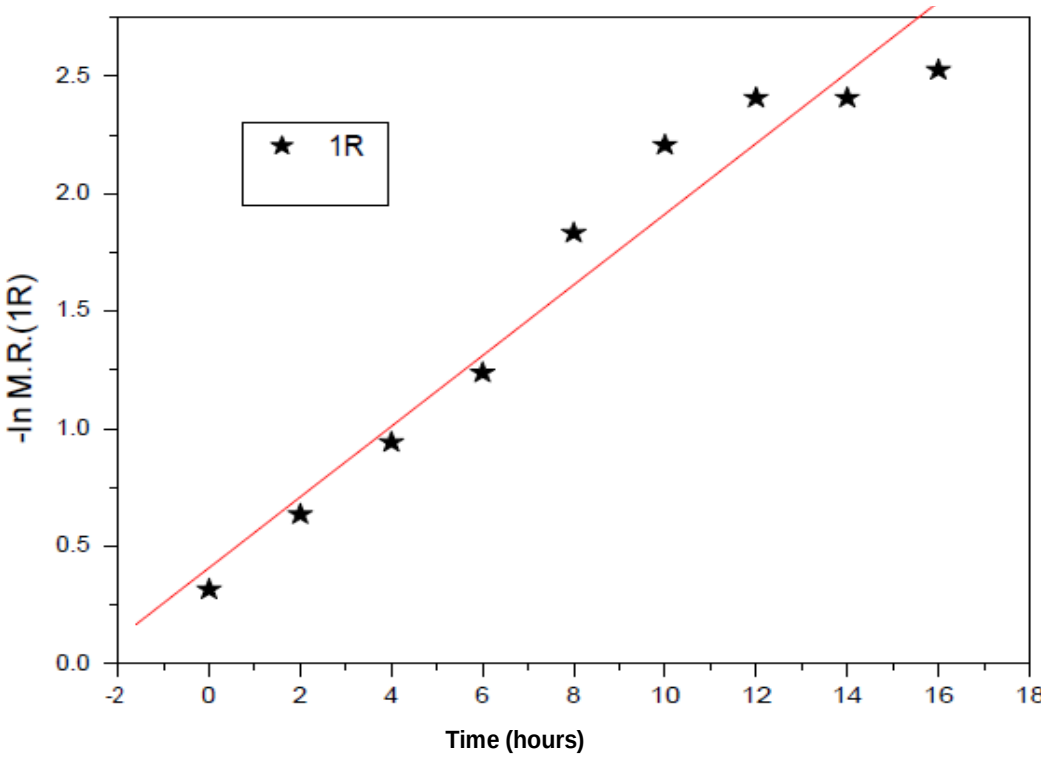

Figure 10. Variation of efficiencies of the collector system incident radiation with time. C. Eff. (D1): collector system efficiency on the first day of drying; C. Eff. (D2): collector system efficiency on the second day of drying. (1R): plot for top tray right; (1L): plot for top left tray; (6R): plot for middle left tray; (6L): plot for middle right tray; (10R): plot for bottom right tray; (10L): plot for bottom left tray.

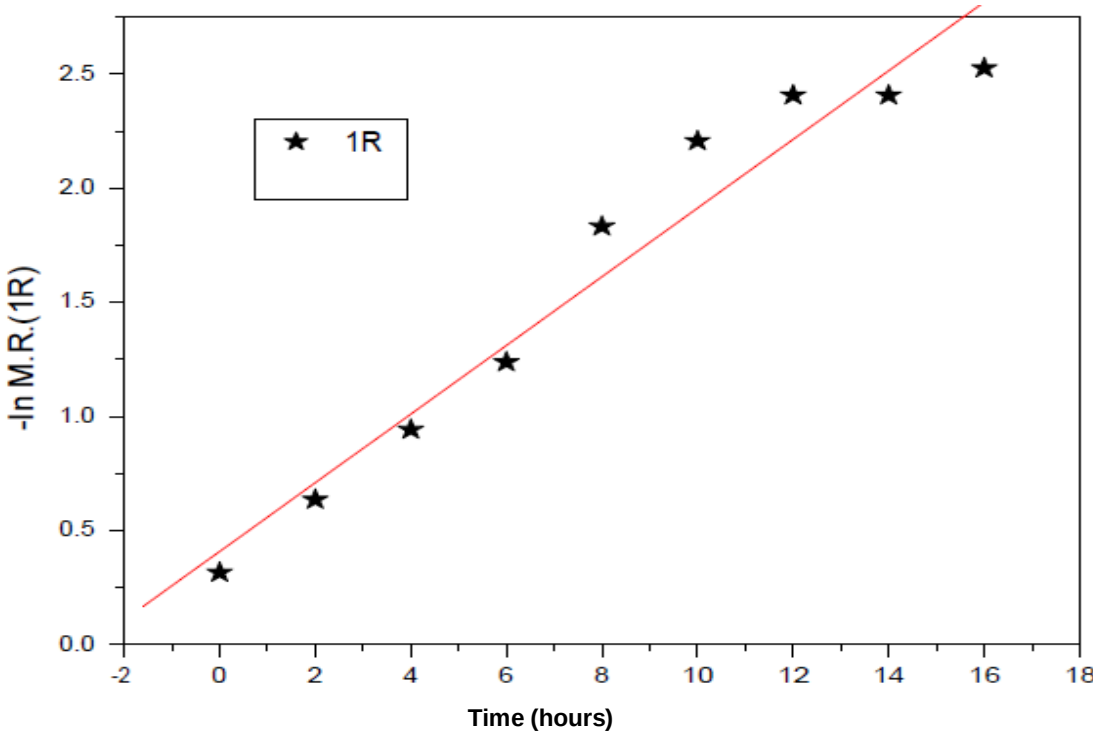

Figure 11. The plot of –ln M.R. versus time for top right tray. (1R): plot for top tray right; (1L): plot for top left tray; (6R): plot for middle left tray; (6L): plot for middle right tray; (10R): plot for bottom right tray; (10L): plot for bottom left tray.

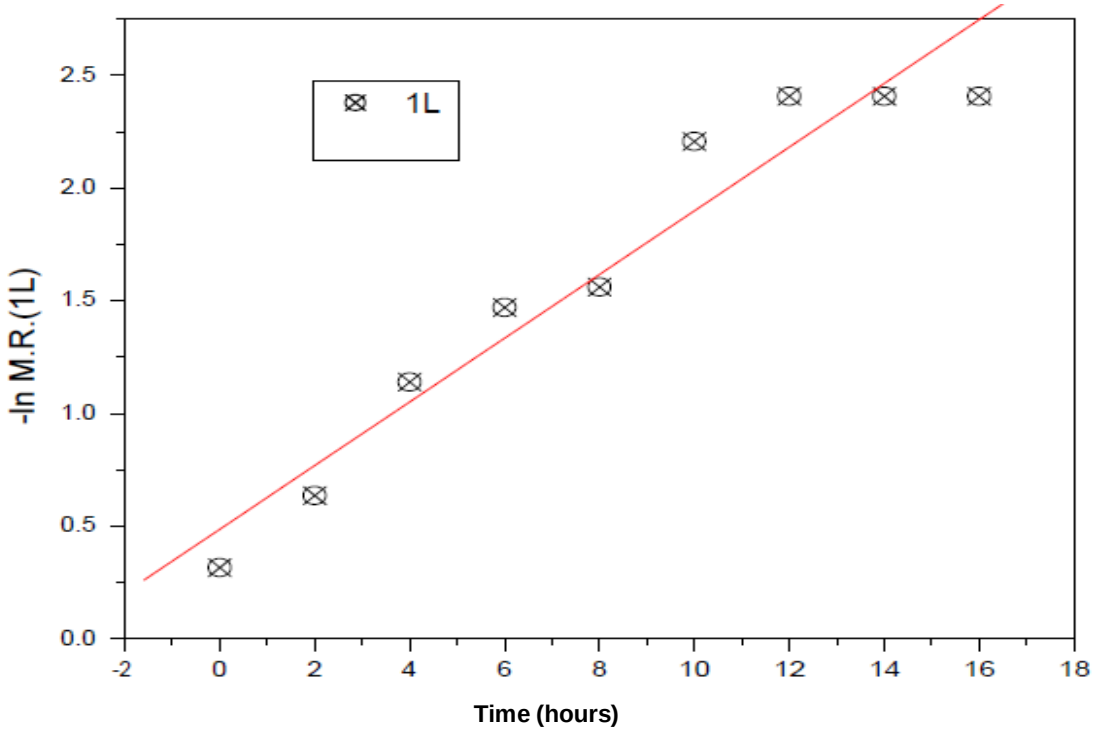

Figure 12. The plot of –ln M.R. versus time for the top left tray. (1R): plot for top tray right; (1L): plot for top left tray; (6R): plot for middle left tray; (6L): plot for middle right tray; (10R): plot for bottom right tray; (10L): plot for bottom left tray.

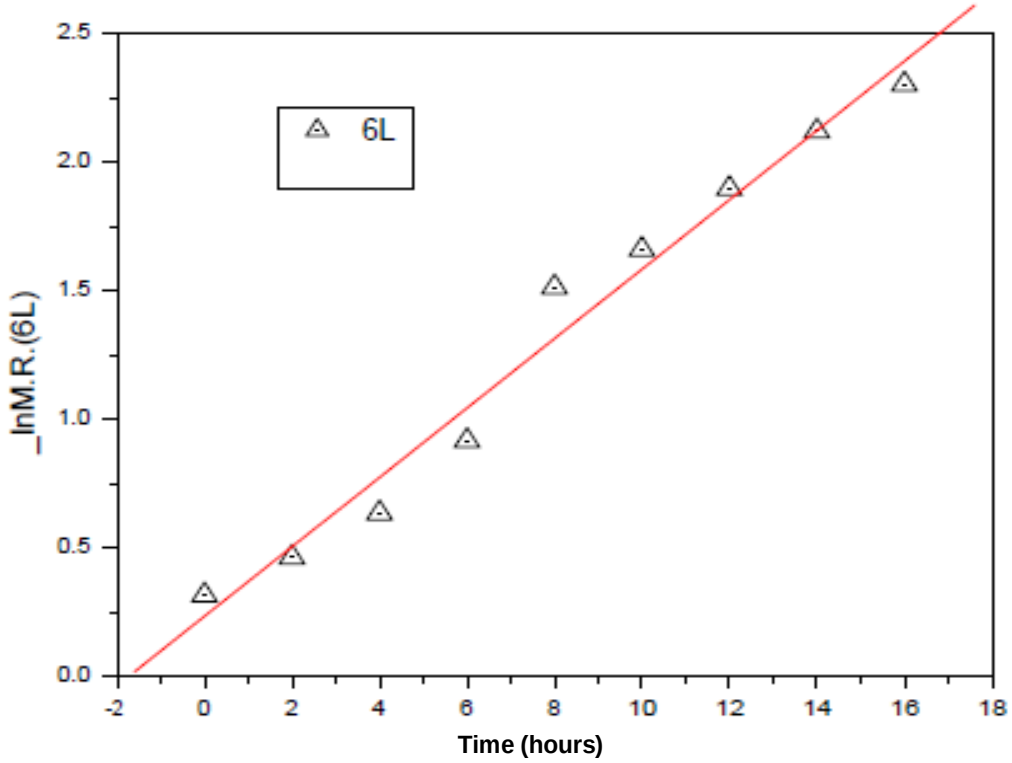

Figure 13. The plot of –In M.R. versus time for the middle left tray. (1R): plot for top tray right; (1L): plot for top left tray; (6R): plot for middle left tray; (6L): plot for middle right tray; (10R): plot for bottom right tray; (10L): plot for bottom left tray.

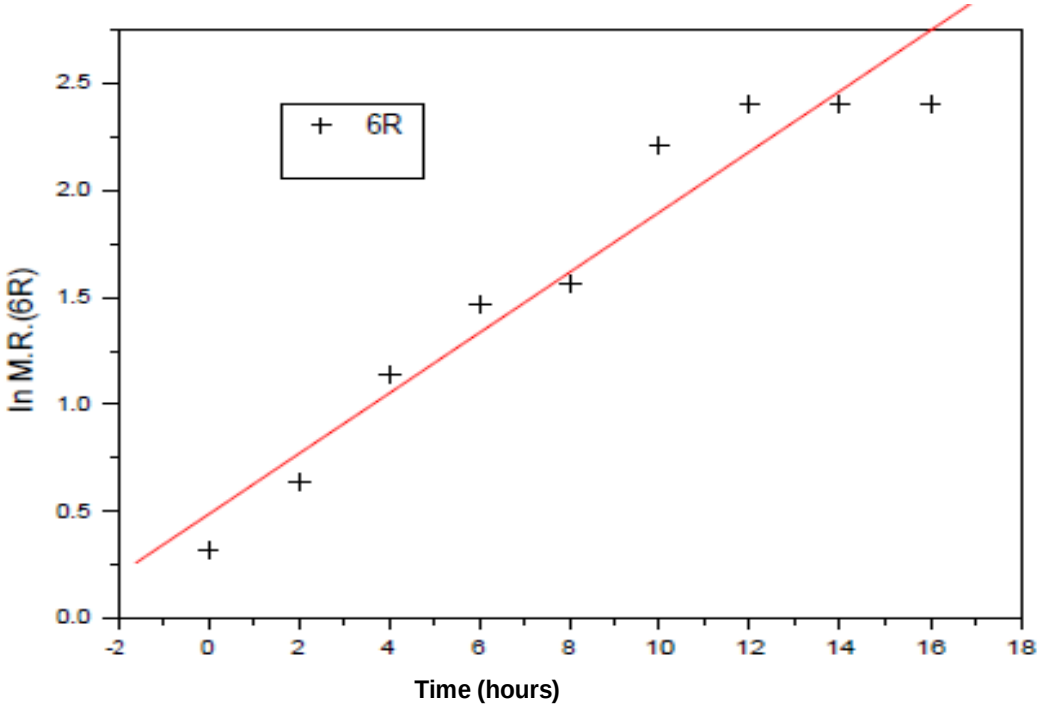

Figure 14. the plot of –In M.R. versus time for the middle right tray. (1R): plot for top tray right; (1L): plot for top left tray; (6R): plot for middle left tray; (6L): plot for middle right tray; (10R): plot for bottom right tray; (10L): plot for bottom left tray.

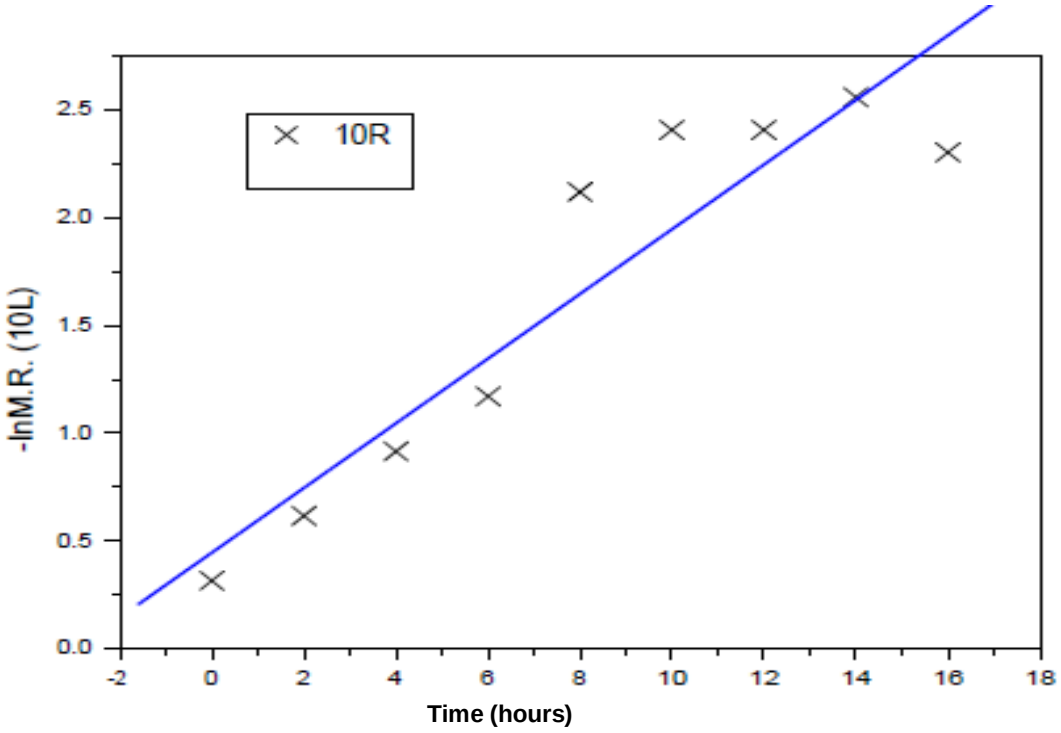

Figure 15. The plot of –ln M.R. versus time for the bottom right tray. (1R): plot for top tray right; (1L): plot for top left tray; (6R): plot for middle left tray; (6L): plot for middle right tray; (10R): plot for bottom right tray; (10L): plot for bottom left tray.

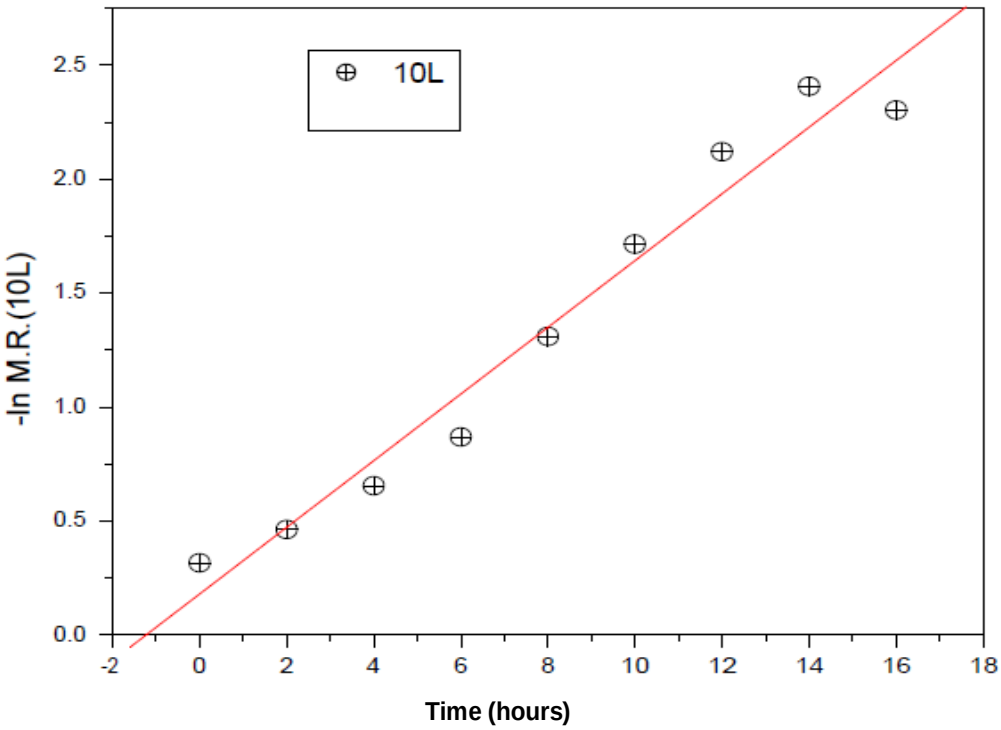

Figure 16. The plot of –ln M.R. versus time for the bottom left tray. (1R): plot for top tray right; (1L): plot for top left tray; (6R): plot for middle left tray; (6L): plot for middle right tray; (10R): plot for bottom right tray; (10L): plot for bottom left tray.

thermal efficiency of the collector system has maximum and minimum values of 19.96% at about 11:30 h and 5.30% at 16:00 h respectively on the first day and 19.3% at 12:30 h and 4.33% at 11:15 h for maximum and minimum values, respectively, on the second day. The mean collector efficiencies calculated according to equation 6 were found to be: 10.5 ± 2.95 % and 9.36 ± 3.95% on the first and second days respectively, while the mean drying system efficiency was computed according to Equation 7 and found to be: 9.93 + 3.53 %.

Conclusions

The twin collector (5.0 m^2 glazing area) indirect forced convection solar dryer was designed and the performance tested for the drying of *Rastrineobola argentea* fish. The drying tests were conducted with 10 kg batches of the fish, between 09:00 and 16:00 h on each day at mean ambient and drying chamber temperatures of 26.5 and 39°C, respectively. The temperature of the drying chamber in the indirect forced convection solar dryer was increased by an average of 12.5°C above the mean ambient value, while the relative humidity of air in the chamber was reduced by an average value of 23.4% at an average air mass flow rate of 0.0163 kg/s and 496 W/m^2 mean incident solar radiation, under full load conditions. The mean thermal efficiencies of the collector and drying system were found to be between 12.63 and 9.93%. Drying of the fish occurred in the falling and constant rate periods, with the moisture content being reduced from 73% w. b. to between 8% w. b. and 10% according to the location in the drying chamber in approximately 11 hours in the solar dryer while open sun drying took 2 days to reach the same moisture content. The average drying rate constant for *Rastrineobola argentea* fish was found to be 0.167 h^{-1}, while the effective moisture diffusivity was found to be 1.36×10^{-3} m^2/s at an average air mass flow rate of 0.0163 kg/s. The overall quality and appearance of the solar dried fish was found to be better than sun dried samples.

Conflict of interests

The authors did not declare any conflict of interest.

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Quality characteristics of African locust bean fruit pulp cakes

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Quality attributes such as proximate, functional and sensory qualities of wheat/African Locust bean fruit pulp cakes were investigated. Cakes were produced from ratios of 100:0, 75:25, 25:75 and 0:100 for African locust bean fruit pulp and wheat flour, respectively, with cake from 100% wheat flour used as a control. Samples were analyzed for proximate composition and sensory properties within 24 h of sample production. Flour blends were also analyzed for functional properties. Moisture, ash, fat, crude fibre and carbohydrates showed an increase in value with increase in substitution of wheat for African locust bean fruit pulp flour, while protein showed a decrease in value with increased substitution. Moisture ranged from 6.19 to 6.31%, ash from 1.42 to 2.07%, fat from 1.42 to 16.02%, crude fibre from 1.03 to 2.52% and carbohydrate ranged from 66.05 to 67.08%. Protein decreased from 8.30 to 8.07%. The functional properties of the flour blends also varied. Oil absorption ranged from 1.25 to 1.43%, water absorption from 1.33 to 1.56% as the substitution level increased. Bulk density decreased from 0.65 to 0.28%, and emulsion capacity from 80.30 to 70.50%. The gelation temperature was from 70.0 to 64.0°C. The results of sensory evaluation showed that the mean scores for taste ranged from 5.7 to 8.1, colour 6.2 to 8.2, texture 6.0 to 8.5 and overall acceptability from 5.8 to 8.3. The result shows that there was no significant (P<0.05) difference between the control and samples with 25% substitution in all the parameters investigated. Hence, acceptable cake can be produced at 25% substitution with African locust bean fruit pulp flour.

Key word: Quality, cake, characteristics, locust bean, fruit pulp.

INTRODUCTION

Cake is a product made from wheat flour, sugar, fat, baking powder and egg. It is a snack that is usually sweet and often baked (Eke, et al.,2008). It is also described as a desirable, delicate, tender, highly sweetened, non-yeasted baked product, (Okaka, 2005). Cake is a baked batter made from sugar, egg, shortenings, milk and leavening agent, mixed together in such a way as to produce a fluffy, fine grained baked product (Victor et al., 1995). Cake is often the desert of choice for meals at ceremonial occasions, particularly wedding anniversaries and birthdays (Eke et al., 2008).

In search for plant protein and vitamin substitute, the African locust bean (*Parkia biglobosa*) has found very popular use especially in fermented 'Dawadawa' which is

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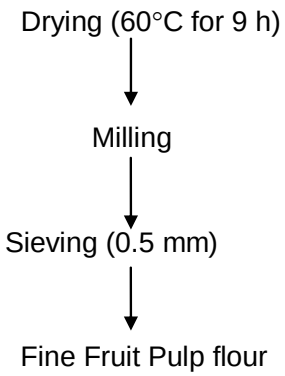

Figure 1. Flow chart for the production of locust bean fruit pulp (Adopted method of Gernah et al., 2007)

the product of the seed. However, the yellow dry powdery pulp called “Dorowa” in Hausa language in Nigeria, has not attracted much attention. According to Uwaegbute (1996), the powdery fruit pulp contains more carbohydrate than the seeds. Similarly, Agu et al. (2007) reported that the carbohydrate of the pulp is primarily reducing sugar (19%), non-reducing sugar (9%) and other complex carbohydrate (36%). Locust bean pulp is sweet to taste which indicates the presence of natural sugar and thus a potential energy source. The attractive yellow colour indicates the presence of phyto-nutrients, possibly carotenoids, which are important precursors of retinol (Vitamin A). The pulp has a sour taste which indicates the presence of ascorbic acid (Vitamin C) (Gernah et al., 2007). The pulp is used in rural Africa during emergencies when the grain stores are empty which is an indication of its edibility and non-toxicity (Akoma et al., 2001).

The use of locust bean fruit pulp for the production of baked products will help to reduce total dependence on imported wheat and increase the utilization of the pulp and create variety. The aim of this study was to produce cake from African locust bean fruit pulp and wheat composite flour and to evaluate the functional, proximate and sensory qualities of cake so produced.

MATERIALS AND METHODS

Source of raw materials

The locust bean fruit pods were bought from Kasuwan Magani, a village in Chukun Local Government Area of Kaduna State. Wheat flour (Dangote Brand), baking powder, sugar, butter, egg and salt were bought from a commercial store in Abubakar Gumi Central Market, Kaduna.

Preparation of locust bean fruit pulp flour

Locust bean fruit pulp flour was prepared using the method of Gernah et al. (2007), as shown in Figure 1. The outer brown cover of the pods was manually stripped open and the yellow fruit pulp was separated from the seeds embedded within the pulp. The yellow pulp was dried in a hot air oven (GENLAB WIDNES, Model T1211) at 60°C for 9 h to a moisture content of 10%. The dried powder was milled with a laboratory hammer mill (Christy Hunt, England), and sieved through a 0.5 mm screen to obtain a fine flour. The flour was package in low density polythene bags and stored in air-tight container at room temperature.

African locust bean fruit pulp

Formulation of blends

Blends of different proportions of wheat flour (WF) and locust bean fruit pulp (LBFP) flour were produced with 100% wheat flour as the control (Table 1). Four recipe formulations were developed. Locust bean fruit pulp (LBFP) flour replaced wheat flour at 100, 75, 25 and 0% levels. These formulations were used for cake preparation following the method of Victor et al. (1995).

Preparation of locust bean fruit pulp cake

Cake samples were prepared using the recipe formulated above. The creaming method was used for the preparation of cake following the method described by Eke et al. (2008) and Anon (2004), using wheat-locust bean fruit pulp flour blend, sugar, margarine, baking powder, egg and salt. Figure 2 shows the production method.

Proximate analysis

Proximate composition (moisture, ash, fat, fibre, protein and carbohydrate) of the cake samples was determined by the AOAC (2000) methods.

Functional properties of the flour blends

The emulsion capacity was determined by the modified method of Okezie and Bello (1988). One gram of sample was suspended in 34 ml distilled water and blended for 30 s in a high-speed homogenizer. Refined vegetable oil (turkey brand, density 0.9008 g/ml) was added at the rate of 5 ml/min and stirred for 3 min. The mixture was transferred to a 50 ml graduated centrifuge tubes and centrifuged at 2500 rpm for 30 min. There was separation into two distinct layers. Emulsion capacity was expressed as gram of oil emulsified per gram of flour.

Oil absorption capacity was determined by a modified method of Beuchat (1977). One gram of flour was mixed with 10 ml of oil in a Kenwood blender for 30 s. The samples were allowed to stand at 25°C for 30 min and centrifuged at 3500 rpm for 30 min. The supernatant was decanted into a measuring cylinder and the volume noted. The oil absorption capacity was calculated as, oil absorption = initial volume of oil used – volume decanted.

Bulk density was determined using the method of Okezie and Bello (1988). A previously cleaned, dried and weighed measuring cylinder was filled to the 10ml mark with the flour samples. The bottom of the cylinder was tapped gently but repeated on a laboratory bench until there was no further reduction of sample level. The cylinder with the sample was weighed and the weight of the sample was determined. Bulk density was determined by:

$$Bd = \frac{W_2 - W_1}{V}$$

Table 1. Recipe formation.

Ingredient	Quantity (g)
Flour (different ratios)	100
Fat	60
Granulated sugar	64
Milk powder	10
Baking powder	1.25
Whole liquid egg	7.5
Banana Essence flavor	1.25

Source: Clark and Herbert (1989).

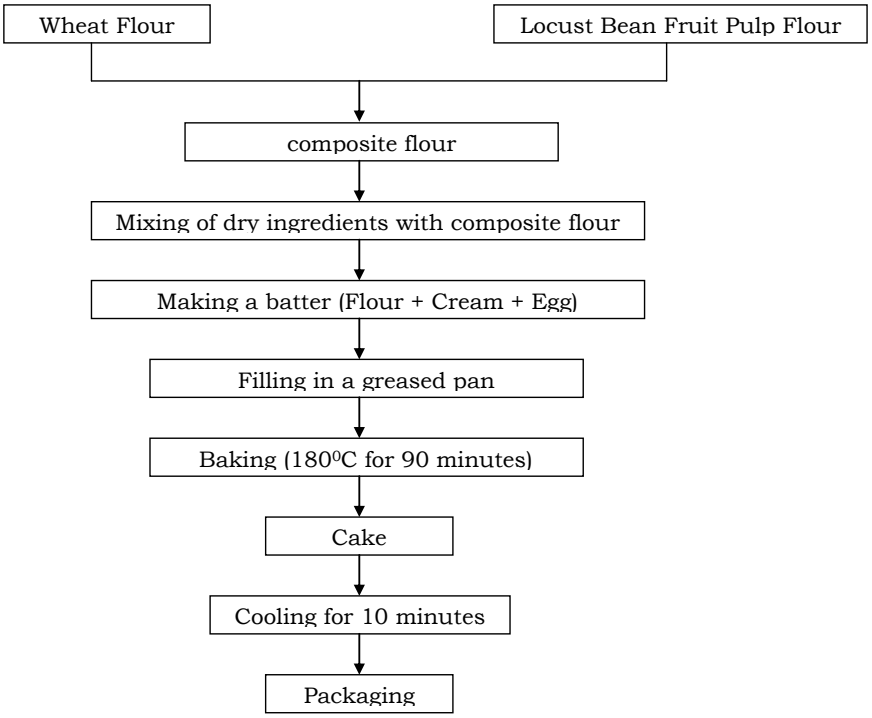

Figure 2. Flow chart for the production of cake.

Where, Bd = Bulk density; W_1 = Weight of empty cylinder; W_2 = Weight of empty cylinder + Weight of sample; V = volume of the cylinder occupied by sample.

Gelling capacity was determined by the method of Narayana and Rao (1982). Three grams of flour samples were dispersed in distilled water in a 25 ml beaker and made up to 30 ml.

A thermometer was clamped on the retort stand with its bulb submerged in the suspension, with magnetic stirrers. The system was heated with a heating mantle. The heating and stirring continued until it began to gel and the corresponding temperature was recorded.

Sensory analysis

Sensory evaluation of the cake samples was conducted within 24 h of baking in nutrition kitchen of the Department of Food Technology, using a panel of 15 untrained members consisting of both staff and students of the Department of Food Technology. The panel was asked to score the products for taste, colour, texture and overall acceptability, using a 9-point Hedonic scale, where 9 represents like extremely and 1 represents dislike extremely. The pattern adopted was as described by Iwe (2002).

Statistical analysis

The mean scores of triplicate determinations were analyzed statistically using analysis of variance using SPSS version 17.0 and mean difference separated using the method of the Ihekoronye and Ngoddy (1985).

RESULTS AND DISCUSSION

The result of proximate composition of cake samples from composite blends of locust bean fruit pulp and

Table 2. Proximate composition of the cake samples.

LBFP	WF	Moisture (%)	Ash (%)	Fat (%)	Crude fibre (%)	Protein (%)	CHO (%)
100	0	6.31±0.21[a]	2.07±0.05[a]	16.02±0.02[c]	2.52±0.00[a]	8.07±0.02[a]	67.08±0.00[a]
75	25	6.23±0.14[a]	1.97±0.09[b]	15.96±0.01[d]	2.03±0.02[b]	8.11±0.00[a]	65.70±0.02[b]
25	75	6.20±0.12[a]	1.46±0.01[c]	16.72±0.07[b]	1.06±0.00[c]	8.21±0.01[a]	66.35±0.01[c]
0	100	6.19±0.01[a]	1.42±0.00[d]	17.01±0.02[a]	1.03±0.03[d]	8.30±0.00[a]	66.05±0.03[d]

Means ± SD; LBFP, Locust bean fruit pulp flour; WF, wheat flour; CHO, carbohydrate; SD, standard deviation.

Table 3. Functional properties of flour blends.

LBFP	WF	Oil absorption (%)	Water absorption (%)	Bulk density (G/ml)	Emulsion capacity (%)	Gellation temperature (%)
100	0	1.43±0.00[a]	1.56±0.01[a]	0.28±0.00[d]	70.50±0.06[d]	64.0±0.01[d]
75	25	1.42±0.01[b]	1.42±0.03[b]	0.37±0.09[c]	72.95±0.09[c]	65.50±0.06[c]
25	75	1.30±0.00[c]	1.35±0.02[c]	0.56±0.05[b]	77.85±0.02[b]	68.50±0.01[b]
0	100	1.25±0.05[c]	1.33±0.02[d]	0.65±0.09[a]	80.30±0.04[a]	70.00±0.02[a]

LBFP, Locust bean fruit pulp flour; WF, wheat flour.

wheat flour is shown in Table 2. The moisture content of the cake samples ranged from 6.20 to 6.31%. The moisture content increased as the proportion of locust bean fruit pulp flour increased. There was no significant difference ($p<0.5$) in moisture content. The increase in moisture could be attributed to the initial high moisture content of locust bean fruit pulp flour. The slight increase in moisture with the increased proportions of locust bean fruit pulp flour could also be due to high sugar content of locust bean fruit pulp flour, which made the cake samples more hygroscopic. The ash content also varied. The ash content varied from 1.42 to 2.07%. The higher the proportion of locust bean fruit pulp, the higher the percentage of ash. The increase in ash content is an indication of high level of minerals in locust bean fruit pulp flour. Slight increases were observed in crude fibre content. This is good because fibre will add bulk and thereby facilitate bowel movement and hence prevents many gastrointestinal diseases in man (Gernah et al., 2007). Slight variations were also observed for fat and carbohydrate contents. The fat varied from 15.96 to 17.01%. The variation is significant at 5% level of probability. The carbohydrate of the products also varied from 65.70 to 67.08%. The result indicated that African locust bean fruit pulp is high in carbohydrate content.

The result of functional properties of the flour blends is shown in Table 3. Oil absorption capacity ranged from 1.25 to 1.45%, bulk density ranged from 0.28 to 0.65 g/ml emulsion capacity from 70.5 to 80.30% and gelling temperature from 64 to 70°C. Water absorption capacity ranged from 1.33 to 1.56%.

Water and oil absorption capacities increased with increasing addition of locust bean fruit pulp. The water absorption capacity shown on Table 3 shows that locust bean fruit pulp flour can be incorporated in aqueous food formulations especially those involving dough handling. The result agreed with the work of Ubbor and Nwaogu (2010). Good water absorption and retention also suggests better performance in texture of comminuted meats and baked products (Okezie and Bello, 1998).

Oil absorption capacity is an important property in food formulations. The value for oil absorption capacity is in agreement with the report of Ubbor et al. (2010). The ability of food to absorb oil enhances sensory properties such as flavor retention and mouth feel. Oil absorption ranged from 1.25 to 1.43%.

The bulk density decreased with increased proportion of African locust bean fruit pulp flour. This indicates that the flour will be a good ingredient in baby food formulations. Bulk density has also been reported to be important relative to sensory acceptability, handling and packaging requirement and shipping cost (Maga and Kim, 1989). The high emulsion capacity of 70.5 to 80.3% was an indication that flour samples could act as excellent emulsifiers in various foods. Emulsification activity is also recognized as an important property in certain applications such as butter, milk and frozen desserts (Ubbor and Nwaogu, 2010). The gelling temperature depends on the carbohydrate contents of food. Wheat flour has the highest gelling temperature as shown on the Table 3. Gelation affects digestibility and texture of starch containing foods (Rickard et al., 1991; Lawal et al., 2004). The variation in gelling temperature may be attributed to compositional similarities especially with regards to their starch content (Ubbor and Nwaogu, 2010).

Table 4. Result of sensory evaluation of cake samples.

LBFP	WF	Taste	Colour	Texture	Overall acceptability
100	0	6.3[a]	6.2[b]	6.0[c]	5.9[b]
75	25	5.7[ab]	6.5[b]	6.7[b]	6.8[b]
25	75	8.1[a]	7.8[a]	8.5[a]	8.2[a]
0	100	7.3[a]	8.2[a]	8.2[a]	8.3[a]
LSD	3.78	1.78	0.35	1.08	

Means not followed by the same letter in the same column are not significantly difference (P≤0.05). LSD, least significant difference; LBFP , locust bean fruit pulp; WF, wheat flour.

Table 5. Weight and volume of the cake samples.

LBFP	WF	Weight (g)	Volume (cm^3)
100	0	67.05±0.03[a]	173.00±0.07[b]
75	25	67.03±0.00[a]	172.02±0.05[b]
25	75	67.02±0.01[a]	171.04±0.03[a]
0	100	67.00±0.01[a]	170.01±0.02[a]
LSD		1.08	4.05

Sensory characteristics of the cake samples

The results of the sensory evaluation of the cake samples are shown in Table 4. The cake samples produced from 100% wheat flour and those produced from 75:25 wheat/African locust bean fruit pulp flour composites had significantly higher (P≤ 0.05) scores for all the parameters investigated. No significant difference (P ≤ 0.05) was observed between them in all the sensory parameters tested. This indicates that the wheat flour can be substituted up to 25% substitution level with African locust bean fruit pulp flour without altering the sensory characteristics as well as consumer acceptability of the cake. Such substitution of wheat flour with non-wheat flours have been suggested by previous authors (Ihediohanma et al., 2009; Akpapunam and Darbe, 1994; Akubor et al., 2000; Gacco and D'Appolanio, 1978).

Physical characteristics

The mean values for the weight and volume of the cakes are shown on Table 5. The weight of the cakes ranged from 67.00 to 67.05 g and no significant difference (P≤ 0.05) existed between the weight of the samples. This was so because the same quality of batter was used for each of the sample. The same trend was observed for volume of cakes which ranged from 170.01 to 173.00 cm^3. There was also no significant difference in the volume (P<0.05) of the cake samples. Cake does not require extensive dough development process which is common with yeast fermented products such as bread. This was responsible for no significant difference in volume of cakes from composite flour of African locust bean fruit pulp flour and wheat flour and those from purely wheat flour. This suggests that variations in the composition in the ratio of wheat flour and African locust bean fruit pulp have no significant difference in both weight and volume of the cakes so produced.

Conclusion

The results of this study has shown that African locust bean fruit pulp can be used in composite with wheat flour, up to 25% substitution level in the production of cake without altering the sensory characteristics and acceptability of the products. The research has also shown that the flour of the locust bean fruit pulp can be utilized in the production of other confectionaries and baby food formulations. It is therefore recommended that 25% African locust bean fruit pulp flour substitution be used by bakers to produce cakes and other confectionaries. This will help to reduce the cost of importation of wheat and create variety in cake and confectionary products.

Conflict of Interests

The author(s) did not declare any conflict of interests.

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Nutritional evaluation of cashew (*Anacardium occidentale,* l.*)* nut protein concentrate and isolate

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This study evaluated the nutritional qualities of a protein concentrate and an isolate produced from cashew nut. The nutritional qualities were evaluated by determining amino-acid composition, *in vitro* digestibility and anti-nutritional factors (tannins, trypsin inhibitor activity-TIA and phytic acid content) in the protein concentrate and isolate using standard analytical methods. The amino-acid with the highest concentration in defatted cashew nut powder (DCNP), cashew nut protein concentrates (CNPC), and cashew nut protein isolate (CNPI) was glutamic acid, which was found to be 22.5, 21.38, and 21.81 g/100 g, respectively. This was followed by leucine, aspartic acid and arginine, in that order. The amino-acid with the lowest concentration in DCNP, CNPC, and CNPI was cysteine. The sulphur-containing amino-acids and some other essential amino-acids (lysine, tryptophan, leucine, isoleucine, and tyrosine) in CNPI were not significantly different ($p>0.05$) from that of DCNP, but were significantly different from that of CNPC ($p<0.05$). CNPC and CNPI were rich in essential amino-acids, and based on the FAO/WHO recommended essential amino-acids pattern requirements for an infant, the limiting amino-acid in CNPC, and CNPI was lysine with chemical scores of 0.68, and 0.63 respectively. However, the anti-nutritional factors (tannins, TIA, and phytic acid contents) of CNPI were found to be lower than those in DCNP and CNPC, while those of CNPI and CNPC were within the range found in the commercial peanut and soy protein concentrates and isolates. The highest *in vitro* digestibility was observed in CNPI (95.30%), while CNPC (87.83%) had a higher value than DCNP (79.93%). The nutritional qualities of the protein concentrate and isolate from cashew nut were found to be comparable to those reported for commercial peanut and soy protein concentrates and isolates. Therefore, the cashew nut products could be suitable as additional source of protein ingredients in food formulations.

Key words: Cashew, protein, nutrition, isolate, concentrate.

INTRODUCTION

Proteins utilised in food processing are of various origins, and can be roughly grouped into animal proteins (gelatin), vegetable proteins (peanut protein), and animal-derivative proteins (milk proteins) (Penny, 1999). Protein concentrates and isolates are used for functional and nutritional food applications in consumer foods (Lin, 1997). Proteins that are essential to growth and health are currently required more in developing countries of the world, because of prevalent outbreak of protein-energy malnutrition in these countries (FAO, 1997). Animal proteins, which are of higher quality and the choice of most individuals, are becoming more expensive to produce.

Supply shortages plus high prices have caused restriction of animal protein consumption in the diets of many families in developing countries of the world (Penny, 1999). However, vegetable proteins which are cheaper and available, offer great potential as a direct food for human consumption.

Cashew is of considerable economic importance because its components have various economic uses. For example, cashew apple is used as an ingredient in the production of cashew beverages and spirits, while cashew kernel is of high food value with about 40-57% oil and 21% protein content (Fetuga et al., 1975). Cashew nut is an important delicacy, which is mainly used in confectionery and as a dessert nut. It was shown that the powdered milk used in the standard milk chocolate recipe can be replaced with 25% roasted cashew kernel (Ogunwolu and Akinwale, 2003).

A recent survey jointly carried out by the Cocoa Research Institute of Nigeria (CRIN) and Bio-hybrids Agriculture Systems Ltd, UK, showed that the number of cashew farmers is increasing yearly while the areas of land cultivated to the crop has increased considerably (Topper et al., 2001). Also, it was reported that the annual raw cashew nut production in Nigeria increased from 727 tons in 1970 to 70,000 tons in the year 2000 (FAO, 2001).

In view of increasing production and limited utilization of cashew globally, and inadequate intake of protein particularly in Africa, where animal proteins are unaffordable by most inhabitants, the cashew kernel is being considered as a suitable raw material to produce protein concentrates and isolates for use in human food products. The work presented here evaluates the nutritional quality of the protein concentrate and isolate produced from cashew nut.

MATERIALS AND METHODS

Source of materials

Cashew nuts were obtained from the cashew plots of Cocoa Research Institute of Nigeria, Ibadan, Nigeria. Chemicals and equipment used were from the Laboratories of Applied Biochemistry group of Institute for plant genetics and crop plant research, Gatersleben, Germany and that of Animal Nutrition Department, Institute of Agricultural Research and Training, Ibadan, Nigeria.

Cashew nut processing, cashew nut powder production and protein extraction

Cashew nut processing, production of cashew nut powder, extraction of protein concentrate and isolate were done as described by an earlier publication (Ogunwolu et al., 2010).

High performance liquid chromatography (HPLC) analysis of cashew nut meal and protein fractions for amino acid composition

Sample hydrolysis

Each sample (0.5 mg) was weighed in triplicates, dissolved in 100 µl of 6 N HCL and 1 µl phenol in vials. Each vial was flushed with nitrogen gas for 1 min, and the vials were sealed, vortexed and dried in heating block (BIOBLOCK Scientific, model 92675-Thermolyne corp. USA) at 110°C for 24 h. The samples were allowed to cool to room temperature.

Reconstitution and derivatization of samples

The samples were evaporated to dryness. To each sample, 200 µl of 20 mM HCL was added, vortexed, centrifuged, and the supernatant removed. A (70 µl) aliquot of (AccQ. Fluor Borate buffer) was added to 10 µl of each sample in the sample tube and vortexed. Derivatization buffer (20 µl) was added to each tube, vortexed, and allowed to stay for 1 min. Samples were transferred to an auto sampler vial (low volume insert) and capped with silicon-lined septum. The vials were heated in a heating block at 550°C for 10 min.

Analysis

Sample diluents were added to each above prepared sample in the tube, mixed and centrifuged (Eppendorf microtube) for 5 min at 5000 rpm. Each sample (30 µl) was transferred (using pipette) into HPLC vials, closed and loaded into HPLC (Waters with FP1520 intelligent florescence detector and water 717 plus-autosampler). Sample injection volumes (of 2 to 8 µl) were used.

In vitro protein digestibility

This was carried out according to the method described by Hsu et al. (1977). Briefly, each sample (31.25 mg) was dissolved in 5 ml of distilled water and adjusted to pH 8.0 with 0.1 N NaOH while stirring at 37°C. A multi-enzyme solution consisting of 1.6 mg trypsin, 3.1 mg chymotrypsin, and 1.3 mg peptidase per 1 ml of distilled water, was maintained in an ice bath and adjusted to pH 8.0 as described above. An aliquot (0.5 ml) of the multi-enzyme solution was added to the protein sample solution and stirred, maintaining the temperature at 37°C. The pH of the solution was recorded 10 min after adding the enzyme solution. The *in vitro* digestibility was calculated using the following equation (Hsu et al., 1977):

$$Y = 210.46 - 18.1x$$

Where, Y = *In vitro* digestibility (%) and x = pH of the sample suspension after 10 min digestion with multi-enzyme solution.

Anti-nutritional factors of cashew nut proteins

Tannins content

This was determined using the vanillin-HCl method as described by Bhagya et al. (2006). Catechin that was used as standard was prepared as follows; catechin (2.5 mg) was dissolved in 1 ml distilled water, and the following concentrations prepared; 2.5 µg = 1 µl catechin solution + 999 µl methanol; 5.0 µg = 2 µl catechin

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solution + 998 µl methanol; 7.5 µg = 3 µl catechin solution + 997 µl methanol;10.0 µg = 4 µl catechin solution + 996 µl methanol 12.5 µg = 5 µl catechin solution + 995 µl methanol.

Each sample (500 mg) was extracted with 500 µl methanol at 25°C for 12 h with shaking. Decanted methanol was then made-up to 1.25 ml and filtered using Whatman No. 1 filter paper. Sample extracts (50 µl) were treated with 250 µl of a reagent mixture (1:1 4% vanillin in methanol: 8% concentrated HCl in methanol). Reagent mixture (250 µl) was also added to each standard concentration. These were allowed to incubate at 25°C for 30 min. The colour developed was read with spectrophotometer at 500 nm. Concentration of the standard was then plotted against their measured absorbances, and the regression equation obtained was used to calculate the concentration of tannins as catechin equivalent.

Trypsin inhibition activity (TIA)

This was determined using an enzymatic assay (Bhagya et al, 2006); each sample (250 mg) was extracted with 12.5 ml of 0.01 M NaOH for 3 h with shaking. The sample extracts were diluted 30 times with distilled water. The suspension was maintained between pH 8.4 and 10.0, using 0.1 M NaOH. Trypsin (0.5 ml) solution (1 mg in 50 ml 0.001 M HCl) was added to each sample and incubated at 3°C for 10 min. BAPNA (5 ml) [40 mg of N-α-Benzoyl-DL-Arginine p-nitroanilide hydrochloric acid in 1 ml dimethyl sulfoxide diluted to 100 ml with Tris buffer at 37°C] was added and the reaction was terminated after 10 min by the addition of 0.25 ml of 30% acetic acid. The sample mixtures were then mixed and filtered. The absorbance was measured at 410 nm against the blank. Blank was prepared by mixing 0.25 ml acetic acid with 0.5 ml trypsin 0.5 ml distilled water and 1 ml BAPNA. The absorbance of the pure trypsin solution was also measured under the same conditions. Trypsin inhibitor activity was calculated using the formula:

$$\text{TIA (mg/g)} = \frac{2.632 \times D \times A_1}{S}$$

Where, D = Dilution factor, A_1 = change in absorbance between pure trypsin and sample extracts; S = sample weight (g)

Phytic acid content

This was determined according to the method described by Gullberg et al. (2004); Each sample (100 mg) was extracted using chloroform : methanol : water mixture in the ratio of 20:60:20 ml. The samples were mixed at 4°C and shaken for 20 min. The samples were then centrifuged at 3,000 rpm at 4°C for 10 min. The super-natants were transferred into a new Eppendorf tube, and equal volume (2) of aliquots of each sample were dried in speed vacuum (Refrigerated vapour trap, model; RVT 400 by SAVANT Company, USA) at 35°C for 18 h. Dried pellets were re-suspended in 200 µl of HPLC-water, and the two aliquots were combined. This sample (200 µl) was purified using microtiter plate containing a 10 kDa filter (micron, 10 KD, Millipore). HPLC-water (20 µl) was added to each filter before loading the samples. The filtrates of the samples were then centrifuged at 4°C and 4000 rpm for 60-80 min. The samples were then transferred into HPLC-MS vials. Phytic acid hydrate with calcium (10 mM) from rice was used as a standard: 20 µl each of the samples and standard were injected into the High performance liquid chromatography-mass spectrometer (HPLC-MS).

Statistical analysis

Determinations were made in triplicates; standard errors of the mean (SEM) and analysis of variance (ANOVA) in SPSS (version 10.1, 2000, SPSS Inc., USA) were used to analyse the results. Means were separated using Duncan multiple range test. Significance was accepted at 0.05 level of probability.

RESULTS

Amino-acid composition

Amino-acid composition data of DCNP, CNPC, and CNPI are presented in Table 1. The amino-acid contents of the three samples were similar, even though DCNP generally had higher values than CNPI, which were also higher than that of CNPC. The amino-acid with the highest concentration in DCNP, CNPC, and CNPI was glutamic acid with values of 22.5, 21.38, and 21.81 g/100 g, respectively. Leucine was the second most abundant amino-acid followed in decreasing order by aspartic acid and arginine (Table 1). The amino-acid with least content in the DCNP, CNPC, and CNPI samples was cysteine with values of 1.02, 0.97, and 1.01 g/100 g, respectively (Table 3). The contents of sulphur-containing amino-acids and some other essential amino-acids (lysine, tryptophan, leucine, isoleucine, and tyrosine) in CNPI were not significantly different from those of DCNP, but were significantly different from those of CNPC ($p< 0.05$).

Essential amino-acid contents (mg/g protein) and suggested pattern of amino-acid requirements for infants, and pre-school children (2-5 years)

The essential amino-acid contents of DCNP, CNPC, and CNPI were compared with the two suggested patterns of amino-acid requirements for infants, and pre-school children (2-5 years) (Table 2). The calculated amino-acid scores (Tables 3 and 4) show that DCNP, CNPC, and CNPI were rich in essential amino-acids. Based on the FAO/WHO recommended essential amino-acids pattern requirements for infants, the limiting-amino acid in DCNP, CNPC, and CNPI was lysine with chemical scores of 0.69, 0.68, and 0.63, respectively (Table 3).

Taking into consideration the FAO/WHO recommended pattern of essential amino-acid requirements for pre-school children (2-5 years), the limiting amino-acid in DCNP, CNPC, and CNPI was lysine with chemical scores of 0.78, 0.77, and 0.72, respectively (Table 4).

Anti-nutritional factors and *in vitro* digestibility

Factors adversely affecting digestion and nutrient absorbtion such as Tannin content, TIA, and phytic acid content of DCNP, CNPC, and CNPI are shown in Figure 1. Tannin content of DCNP (1.99%) was found to be higher than that of CNPC (1.82%), which was higher than that of CNPI (0.80%). Trypsin Inhibition activity of the CNPI (0.21 mg/g) was found to be lower than that of

Table 1. Amino-acids composition of defatted cashew nut powder (DCNP), cashew nut protein concentrate (CNPC), and cashew nut protein isolate (CNPI).

Amino acid	DCNP(g/100 g)	CNPC(g/100 g)	CNPI(g/100 g)
Lysine	4.52±0.11[a]	4.18±0.18[b]	4.46±0.12[a]
Histidine	2.69±0.15[a]	2.49±0.10[b]	2.67±0.12[a]
Arginine	10.18±0.16[a]	9.83±0.03[b]	9.95±0.03[b]
Aspartic acid	10.38±0.10[a]	10.21±0.04[b]	10.25±0.05[a]
Threonine	3.46±0.05[a]	3.16±0.02[b]	3.20±0.01[b]
Serine	5.79±0.02[a]	5.21±0.03[c]	5.50±0.02[b]
Glutamic acid	22.50±0.02[a]	21.38±0.03[c]	21.81±0.21[b]
Proline	5.41±0.01[a]	5.23±0.03[c]	5.36±0.01[b]
Glycine	5.35±0.03[a]	5.19±0.01[c]	5.29±0.01[b]
Alanine	4.39±0.01[a]	4.04±0.07[b]	4.15±0.13[b]
Cysteine	1.02±0.03[a]	0.97±0.02[b]	1.01±0.01[a]
Valine	5.58±0.03[a]	5.24±0.04[c]	5.51±0.01[b]
Methionine	2.28±0.02[a]	2.21±0.01[b]	2.27±0.02[a]
Isoleucine	4.18±0.02[a]	4.09±0.01[b]	4.17±0.02[a]
Leucine	11.48±0.02[a]	11.32±0.03[b]	11.47±0.02[a]
Tyrosine	3.32±0.03[a]	3.29±0.01[a]	3.31±0.01[a]
Phenylalanine	4.53±0.02[a]	4.49±0.01[b]	4.51±0.01[b]
Tryptophan	1.38±0.01[a]	1.36±0.01[b]	1.37±0.01[a]

Means followed by the same alphabetic on the row are not significantly different at $p<0.05$.

Table 2. Essential amino-acids contents of defatted cashew nut powder (DCNP), cashew nut protein concentrate (CNPC), and cashew nut protein isolate (CNPI), and suggested pattern of amino-acid requirements for infants and pre-school children (2-5 years).

Amino-acids	DCNP (mg/g protein)	CNPC (mg/g protein)	CNPI (mg/g protein	*Amino-acid requirements for infants (mg/g protein)	*Amino-acid requirements for children (mg/g protein)
Isoleucine	41.8	41.7	40.9	46.0	28.0
Leucine	114.8	114.7	113.2	93.0	66.0
Lysine	45.2	44.6	41.8	66.0	58.0
Tryptophan	13.8	13.7	13.6	17.0	11.0
Valine	55.8	55.1	52.4	55.0	35.0
Methionine +Cysteine	33.0	32.8	31.8	42.0	25.0
Tyrosine	34.6	32.0	31.6	43.0	34.0

* FAO/WHO/UNU (1991).

CNPC (0.59 mg/g), which was lower than that of DCNP (1.91 mg/g). Phytic acid content of the DCNP (6.44 g/kg) was found to be higher than that of CNPC (4.50 g/kg), which was higher than that of CNPI (3.54 g/kg).

Figure 2 shows the *in vitro* digestibility of defatted cashew nut powder (DCNP), cashew nut protein concentrate (CNPC), and cashew nut protein isolate (CNPI). The highest digestibility was observed in CNPI (95.30%), while the in vitro-digestibility of CNPC (87.83%) was found to be higher than that of DCNP (79.93%).

DISCUSSION

Some of the amino-acid contents of DCNP were significantly higher ($p<0.05$) than those of CNPI and CNPC. This is likely a result of different processing steps involved in the production of CNPI and CNPC, and is in agreement with the findings of Lo and Hill (1971) who reported that the amino-acid content of rapeseed meals were higher than that of rapeseed protein concentrate. Also, similar trends were observed in sunflower flour and its concentrate (Canella et al, 1982).

All the three samples (DCNP, CNPC, and CNPI) were found to be rich in essential amino-acids, and when compared with suggested pattern of amino-acid requirements for infants, and pre-school children (2-5 years); lysine was found to be the limiting essential amino-acid. The use of two amino-acid reference patterns was in

Table 3. The chemical score in defatted cashew nut powder (DCNP), cashew nut protein concentrate (CNPC), and cashew nut protein isolate (CNPI) based on amino-acid requirements for infants.

Amino-acids	*DCNP	*CNPC	*CNPI
Isoleucine	0.91	0.91	0.89
Leucine	1.23	1.23	1.22
Lysine	0.69	0.68	0.63
Tryptophan	0.81	0.81	0.80
Valine	1.02	1.00	0.95
Methionine + Cysteine	0.79	0.78	0.78
Phenylalanine + Tyrosine	1.09	1.09	1.08
Threonine	0.81	0.74	0.74
Chemical score	0.69	0.68	0.63
Limiting amino acid	Lysine	LysineLysine	

* Calculated based on recommended pattern for infants FAO/WHO/UNU (1991).

Table 4. The chemical score in defatted cashew nut powder (DCNP), cashew nut protein concentrate (CNPC), and cashew nut protein isolate (CNPI) based on amino-acid requirements for pre-school children (2-5 year).

Amino-acids	DCNP*	CNPC*	CNPI*
Isoleucine	1.49	1.49	1.46
Leucine	1.74	1.74	1.72
Lysine	0.78	0.77	0.72
Tryptophan	1.26	1.25	1.24
Valine	1.59	1.57	1.50
Methionine + Cysteine	1.32	1.31	1.27
Phenylalanine + Tyrosine	1.25	1.24	1.24
Threonine	1.02	0.94	0.93
Chemical score	0.78	0.77	0.72
Limiting amino acid	Lysine	Lysine	Lysine

*****Calculated based on recommended pattern for pre-school children (2-5 yr) FAO/WHO/UNU (1991).

order to include infants in the protein evaluation, which is in accordance with the Food and Agriculture Organisation (FAO) regulation (FAO/WHO/UNU, 1991). The FAO regulation states that amino acid reference pattern for pre-school child (2-5 years) should be used for the evaluation of protein quality for all age categories except infants.

Tannins, TIA, and phytic contents were found to be lowest in CNPI while higher values were recorded for CNPC and CNPI. This may be as a result of processing involved in the production of these products. Reduction in tannin due to processing might have been caused by the activity of polyphenol oxidase or fermenting micro flora on tannins (Reddy and Pierson, 1994). The tannin contents of the samples are within the range of the values reported for commercial peanut protein concentrate and isolate (1.36%) (Fardiaz and Markakis, 1981). This is very important because higher tannin content could make the proteins unavailable for human nutrition. Previous work suggests, protein-tannin complex appeared to be formed by multiple hydrogen bindings between phenolic hydroxyl groups of tannins and carbonyl groups of protein peptides bonds of digestive enzyme, inhibiting proteolytic enzyme activity in the gastro-intestinal track (Bressani, 1983). Trypsin Inhibition Activity is predominantly proteins and located, for the most part, with the main storage proteins in the protein bodies of the cotyledon. Thus trypsin inhibitors tend to fractionate with the milieu of storage proteins as they are processed (Horisberger et al., 1986). This implies that processing may affect the TIA content of the cashew nut, and would explain the differences in the TIA contents of DCNP, CNPC, and CNPI we observed. The trypsin inhibitors are known to have high amounts of cysteine in their structure (Lawrence and Nielsen, 2001), suggesting that a reduction in the cysteine composition of DCNP, CNPC, and CNPI was associated with an

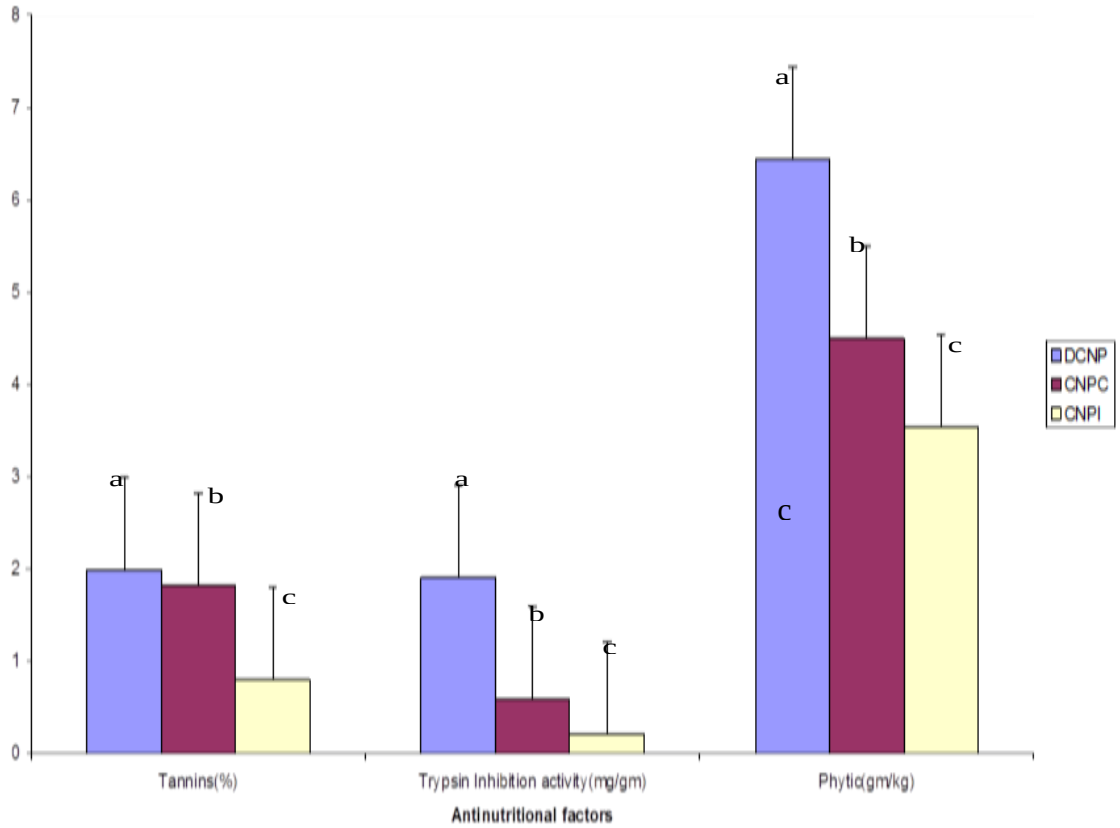

Figure 1. Anti-nutritional factors of defatted cashew nut powder (DCNP), cashew nut protein concentrate (CNPC), and cashew nut protein isolate (CNPI).

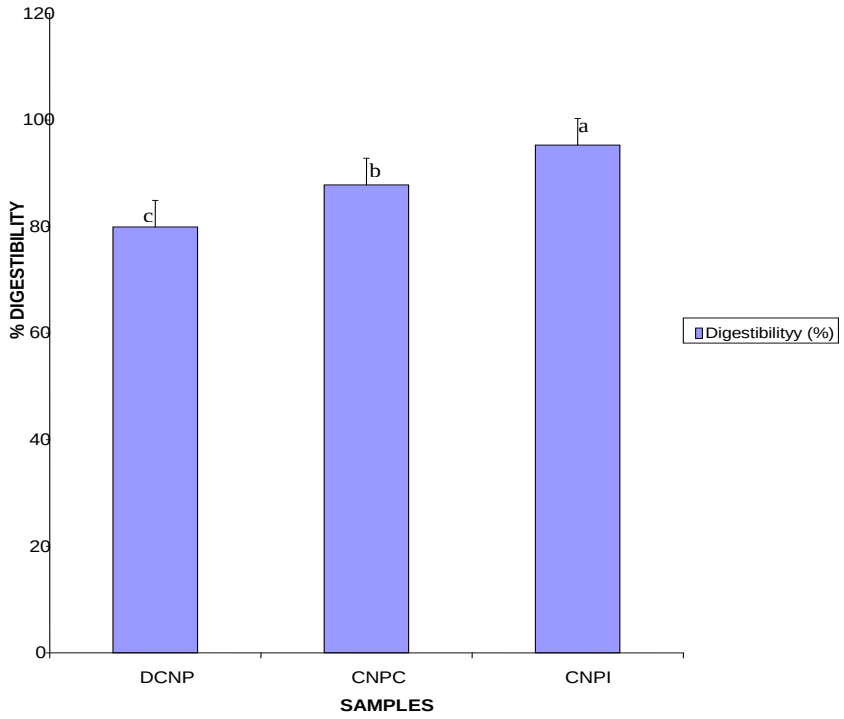

Figure 2. *In vitro* digestibility of defatted cashew nut powder (DCNP), cashew nut protein concentrate (CNPC), and cashew nut protein isolate (CNPI).

observed reduction in protease inhibitory activity of CNPI and CNPC. The higher TIA content of CNPC (which was methanol precipitated) than CNPI could be explained by the reported findings that TIA is methanol soluble (Idouraine et al, 1991). The value of TIA in DCNP, CNPC, and CNPI was lower than that of defatted soy flour (16 mg/g), commercial soy protein concentrate (8 mg/g of protein), and soy protein isolate (1.4 mg/g of protein), as previously reported (Anderson and Wolf, 1995). This is important because TIA factor was found to form complexes with trypsin enzymes thereby impairing its proteolytic activity, which in turn reduced availability of amino-acids for metabolic processes (Liener, 1989). Phytic acid has long been recognised to interfere with the absorption of minerals, especially calcium, magnesium, iron and zinc; phytic acid is also reported to have anti-carcinogenic properties (Messina and Barnes, 1991). The difference in the phytic acid level of DCNP, CNPC, and CNPI could be as a result of the protein level and method of fractionation. According to a previously reported finding (Chau and Cheung, 1997), protein level, process of fractionation, and protein conformation certainly affected the phytic level in the isolated extracts. Also, at alkaline pH, phytate interaction with proteins diminishes, because the lysine and arginine groups lose their charge and thus the capacity to form complexes; also salts like calcium, magnesium are insoluble under alkaline conditions (Martinez-Dominguez et al., 2002). These may explain the reduction in the phytic acid composition of CNPI and CNPC when compared to DCNP. The phytic acid composition of defatted soybean (13.0 g/kg), soybean protein concentrate (12.5 g/kg), and soybean protein isolate (10.1 g/kg) as previously reported (Honig et al., 1984), are higher than the values obtained in this work for DCNP, CNPC, and CNPI.

The *in vitro* digestibility results indicated that CNPI has highest digestibility, followed by CNPC, and then DCNP. This may be as a result of the processing method used, as isoelectric precipitation denatures proteins extracted from legume flours, making them more susceptible to enzymatic attack (Chau and Cheung, 1997). The digestibility value obtained for CNPI (97%) is similar to what was obtained for soy protein isolate (Gilani and Sepher, 2003). The difference in the digestibility of DCNP, CNPC and CNPI could be as a result of the difference in the level of anti-nutritional factors in these samples (Fagbemi et al., 2005). Different interactions have been described between tannins and dietary protein, and tannins and digestive enzymes (Jansman et al., 1994). Also, tannins have the ability to bind dietary protein into an indigestible form (Glick and Joslyn, 1970). Therefore the reduction achieved for the anti-nutritional factors in the CNPC and CNPI when compared to that of DCNP, could be directly related to this improved digestibility. Digestibility of protein is considered a good approximation of the bioavailability of amino acids of mixed diet and properly processed food products that contain minimal amounts of residual anti-nutritional factors (FAO/WHO/UNU, 1991).

Conclusion

The high essential amino-acid composition, high digestibility and low anti-nutrients contents of CNPI and CNPC could make them good protein sources for fortification of a variety of food products to combat protein deficiency in many parts of the world, particularly in developing countries.

Conflict of interests

The authors did not declare any conflict of interest.

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Hygiene practices and food contamination in managed food service facilities in Uganda

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A longitudinal study was conducted to examine individual worker and institutional hygiene practices and bacterial contamination in food service facilities at Makerere University. Questionnaires regarding food service knowledge, attitudes, and practices were administered to 94 individual and institutional respondents from 16 facilities through in-person interviews. A total of 48 samples (3 per facility) were analyzed for evidence of contamination (total aerobic mesophilic bacteria, coliforms, *Escherichia coli, Salmonella*). Respondents with higher education levels had better knowledge and attitudes regarding food safety, but knowledge in specific areas were varied. The majority of individual workers used safe food handling practices, but the majority of institutions did not practice good environmental hygiene. The majority of food samples tested had APC and total coliform levels higher than acceptable, but only two tested positive for *Salmonella.* Food service worker training and managerial improvement of environmental hygiene are needed to improve food safety in these facilities.

Key words: Food safety, food service workers, coliforms, *E. coli.*

INTRODUCTION

Foodborne diseases are a challenge for both developed and developing countries (Da Cunha et al., 2012), and are a leading cause of illness and death in developing countries (Hassan et al., 2010). Despite concerted efforts for several decades, foodborne diseases remain a major global public health issue with substantial morbidity and mortality associated with the consumption of contaminated foodstuffs (Havelaar et al., 2010).

The measurement of the safety of foods has relied on evaluation of the microbiological quality of foods (Havelaar et al., 2010; Jacxsens et al., 2010). Bacterial counts in prepared food or water is a key factor in assessing the quality and safety of food, and can reveal the hygiene level adopted by food handlers in the course of preparation of such foods (Nkere et al., 2011). In a recent review, *E. coli*, *Shigella, Salmonella,* and *Campylobacter* spp. were the most commonly reported causes of gastrointestinal disease in sub-Saharan Africa (Fletcher et al., 2011), and all have been associated with foodborne disease (FDA, 2012). One study conducted in Kampala, Uganda, concluded that the microbiological safety of salads was unsatisfactory due to high bacterial

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counts and the presence of *Staphylococcus aureus*, which were attributed to inappropriate food handling hygiene and sanitation during preparation (Oiko, 2000, unpublished). However, in developing countries, monitoring the microbial safety of foods is not routinely practiced, due to a lack of infrastructure and effective food safety regulations and standards (Nguz, 2007).

Outbreaks of foodborne illnesses have been linked to improper food handling practices at food serving establishments (Baş et al*.,* 2006; Çakiroğlu and Uçar, 2008; Hassan et al., 2010; Da Cunha et al., 2012). The most commonly reported food preparation practices that contribute to foodborne diseases include poor environmental hygiene, inadequate cooking, contaminated equipment, improper holding temperatures and food from unsafe sources (Guzewich and Ross, 1999; Da Cunha et al., 2012).

Food handlers, the people who are employed directly in the production and preparation of foodstuffs, are integral to reducing food safety risks (De Sousa, 2008; Chapman, 2009). Lack of personal hygiene among food handlers is one of the most commonly reported practices that contribute to foodborne illness (Taulo et al., 2009). The majority of foodborne outbreaks associated with food workers have involved transmission of the pathogens to food by the food workers' hands (Guzewich and Ross, 1999; Çakiroğlu and Uçar, 2008), and ensuring personal hygiene, particularly hand washing, has been cited the most effective tool in preventing the spread of foodborne infections (NHS Plus, 2008).

Developing and educating a workforce knowledgeable in food safety and hygiene is necessary to improve food safety in food service establishments. Studies of the knowledge, attitudes and practices of food service workers in developing countries have been conducted, and several trends have been reported in this workforce. Factors that were associated with better food safety knowledge include the level of education of the worker (Zeru and Kumie, 2007; Kibret and Abera, 2012; Onyeheho and Hedberg, 2013), and training in food safety (Garin et al., 2002; Baş et al*.,* 2006; Kibret and Abera, 2012; Olumankaiye and Bakare, 2013; Onyeheho and Hedberg, 2013). Workers in food service establishments in hospitals and schools were also found to have better food safety knowledge and practices than workers in other restaurants, street vendors, and other small food service establishments (Baş et al*.,* 2006; Onyeheho and Hedberg, 2013). Training programs are effective, and improved environmental and worker hygiene practices in a study of fast food and street food vendors in Nigeria (Olumankaiye and Bakare, 2013). However, despite knowledge and awareness of safe food handling methods, several studies have found that food handlers often do not use safe food handling practices, based on observation and microbial food testing (Baş et al*.,* 2006; Zeru and Kumie, 2007; Kibret and Abera, 2012).

Although there is a growing body of research on food safety and food worker hygiene and practices in developing countries, the majority of these studies focus on street food vendors rather than larger institutional food service establishments. Given the reported differences in food safety knowledge and practices between food service facilities in schools and restaurants, this study was conducted to test two research hypotheses: 1) food contamination levels will be significantly lower in facilities where kitchen staff or food handlers practice good hygiene than those that practice poor hygiene; and 2) food contamination levels will be lower in university food service establishments due to better worker hygiene and food safety practices. The objectives of the study were to: describe the knowledge, attitudes and practices of food handlers in food service facilities at a university campus (Makerere University, Kampala, Uganda) and restaurants in its neighborhood; measure levels of food contamination at these facilities through microbiological analyses; and determine the effect of individual hygiene practices on food contamination levels.

MATERIALS AND METHODS

A longitudinal study involving two groups of food service workers and facilities was conducted between September, 2012 and July, 2013. The kitchen staff at Makerere University, working in student halls of residence, comprised Group A (facilities A1-A9), and the neighborhood restaurants that operated in improvised makeshift structures comprised Group B (facilities B1-B7). A proportional random sample was selected for the study: 75 subjects were selected from 95 workers in nine different kitchens at Makerere University and 25 subjects were selected from 35 workers in seven restaurants outside the University. Food samples, consisting of all the items served at the time of sampling, were collected from each facility on three different points during the study period.

Data collection

Face-to-face interviews were conducted to collect information on workers' hygiene practices and attitudes using questions adopted from Baş et al., 2006 and Giritlioglu et al*.,* 2011. Information on food safety practices was collected through a semi-structured questionnaires through in-person interviews by trained study personnel at two levels: the institution level (from the 16 facilities), and the individual level (from food service workers). The institution and individual-level information on food safety practices was collected by questionnaires administered to kitchen supervisors, and individual food service workers. All responses were validated by interviewers' observations of the facilities and respondents, and responses were corrected in situations where observations did not agree with the responses (e.g., there was no soap at hand washing basins but the respondent indicated that soap was provided). Individual respondents were assigned food safety attitude and hygiene practice scores:

$$Attitude_{ij} = \frac{\sum_{j=1}^{16} Response_{ij}}{\sum_{j=1}^{16} MaxResponse_j} \times 100 \qquad Practice_{ik} = \frac{\sum_{k=1}^{12} Response_{ik}}{\sum_{k}^{12} MaxResponse_k} \times 100$$

Where, $Attitude_{ij}$ = attitude score for respondent *i*; $Response_{ij}$ = response of respondent *i* to attitude question *j*; $MaxResponse_j$ = the maximum value of possible responses to attitude question *j* (2 for

yes/no responses); $Practice_{ik}$ = hygiene practice score for respondent i, $Response_{ik}$ = response of respondent *i* to hygiene practice question *k*; and $MaxResponse_k$ = the maximum value of possible responses to practice question *k* (6 for Likert scale questions regarding the frequency of personal hygiene practices; 2 for yes/no responses). The attitude and practice scores could range in value from 0 to 100.

Food sample collection

Food samples were collected from the study kitchens at serving point. Approximately 250-500 g of food were collected and sealed in sterile stomacher bags, placed in cool boxes, and transported to the food safety laboratory at the College of Veterinary Medicine, Animal Resources and Biosecurity (COVAB), Makerere University, within 30 minutes after collection. Samples were processed within 6 hours of collection.

Microbiological analyses

Food contamination was measured by total aerobic mesophilic bacteria plate counts (APC), enumeration of *Escherichia coli (E. coli)* and total coliforms, and presence of *Salmonella.* A 25 g sample was collected from each food sample, and prepared using sterile surgical blades and adding 225 ml of sterile buffered peptone water. Each sample was divided into two, and each sub-sample was placed in sterile stomacher bags and homogenized using a pulsifier. After homogenization, each sub-sample was divided into two, and serial 10-fold dilutions were made, up to 10^{-7} dilution (Harrigan, 1998). Selected dilutions of the food samples were mixed by vortexing, and inoculations were made within 25 min of processing, using methods adapted from Downes and Ito (2001).

For total aerobic mesophilic bacteria (APC) counts, 0.1 ml of the processed food samples of specified dilutions were inoculated onto sterile Plate Count Agar (HiMedia Laboratories, India), using the surface spread method, and incubated for 24 h at 37°C (Refai, 1979; Harrigan, 1998). After incubation, plates containing 25-250 colonies were selected for counting. Counts obtained were characterized by the reciprocal of the dilution factors used, and additionally by 10^1. The bacteria population was expressed as a number of colony forming units per gram (CFU/g).

In processing for total coliforms and *E. coli*, 0.1 ml of the processed food samples of specified dilutions were inoculated onto Chromocult coliform agar (Merck, Germany), a selective indicator media for the enumeration of *E. coli* and other coliforms. After incubation for 24 h at 37°C, dark blue colonies were classified as *E. coli*, while pink colonies were classified as other coliforms (Merck, 1996). Gram staining was carried out on suspected *E. coli* colonies, and all cultures with Gram negative short rods were biochemically confirmed as *E. coli* using the IMVIC tests (Downes and Ito, 2001). Indole production was regarded as positive for *E. coli* if there was an appearance of a distinct red color in the upper layer; the Voges-Proskauer (VP) test was considered positive if the eosin pink color developed; the methyl red test was considered positive if a distinct red color developed; and the citrate utilization test was considered positive if Simmon's citrate media changed from green to blue.

To enhance the recovery of *Salmonella*, samples underwent pre-enrichment for 24 h at 37°C (Refai, 1979). Enrichment in selective media [Tetrathionate Brilliant green broth (Merck, Germany)] was conducted in triplicate for each sample, for 24 h at 37°C (Downes and Ito, 2001). After enrichment, enriched samples were streaked on plates of Xylose Lysine Desoxycholate (XLD) (Oxoid, UK) selective medium, incubated at 37°C for 24 – 48 h, and examined for *Salmonella* colonies which exhibited the typical appearance "i.e. pink with large black centers which made them appear black" (FDA, 2011). Suspect colonies were subcultured to get a pure culture, and were subjected to confirmatory tests (Harrigan, 1998). Confirmation of *Salmonella* was based on results of Gram staining, urease, indole, citrate, and TSI tests (Oxoid, UK).

Statistical analyses

The primary outcomes of interest were the safety status of food in each facility, and the use of unsafe food handling practices at the individual and institutional level. Each employee and institution was classified as having safe food handling practices if they had food hygiene practices and attitude scores of 75% or more. For each facility, foods were classified as safe if the mean APC of the three samples was less than 100,000 CFU/g, and the mean counts for coliforms and *E. coli* were less than 100 CFU/g, using cutpoints for microbiological food safety (Gilbert et al., 2000). There were only two food samples where *Salmonella* was detected, so statistical analyses regarding *Salmonella* were not conducted.

Descriptive statistics were generated to characterize the study respondents, responses to questionnaires, attitude and practice scores, and laboratory testing results. Associations between food service worker characteristics (age, gender, level of education and working experience measured by years in employment) and their attitudes on hygiene were assessed using the chi-square test for associations. Associations between safe food handling status and categorical risk factors were evaluated through odds ratios (OR), with 95% confidence intervals and p-values. Associations between mean APC, coliforms and *E. coli* with different types of food were assessed using the non-parametric Kruskall-Wallis X^2 of the Wilcoxon Rank-Sum test, and associations between unacceptable levels of bacteria with different types of food were assessed using Fisher's Exact 2-tailed test, and the strength of association reported through odds ratios with 95% confidence intervals.

Multivariable logistic regression was used to identify risk factors associated with the safety of foods. Risk factors significantly associated with food safety from the univariable analyses ($p \leq 0.05$) were considered for inclusion in multivariable analysis. Binary logistic regression was used to screen these risk factors – those that were statistically significant ($p \leq 0.05$) were used in the multivariable analysis. Stepwise logistic regression was used to develop the final model for food safety, with adjustment for confounders (Kleinbaum and Klein, 2010).

RESULTS

A total of 94 interviews were conducted, including 54 individual respondents (41 from Group A, 13 from Group B) and 40 institutional respondents (Table 1). The majority of individual respondents were females from 26 to 60 years in age, received secondary level educations, and had worked with food service facilities for more than twelve years. The majority of the individual respondents were food servers and cooks, and only 40.7% of respondents had attended on-the-job training since they joined employment. The 40 institutional respondents (33 from Group A, 7 from Group B) were males from 26 to 60 years in age, received secondary and tertiary educations, and had over 5 years of experience in food service. Chiefs and cooks made up the majority of institutional respondents, and only 35% had attended any on-the-job training.

Safe food handling attitudes and practices

When asked about attitudes regarding food safety, the

Table 1. Characteristics of study respondents.

Factor	Level	Individual (n = 54)		Institutional (n = 40)	
		N	%	N	%
Facility type	A	41	75.9	33	82.5
	B	13	24.1	7	17.5
Gender	Male	19	35.2	24	60.0
	Female	35	64.8	16	40.0
Age	18 – 25	6	11.1	2	5.0
	26 – 35	11	20.4	13	32.5
	36 – 45	17	31.5	8	20.0
	46 – 60	19	35.2	17	42.5
	> 60	1	1.9	0	0
Highest Level of Education	None	1	1.9	0	0
	Primary	19	35.2	2	5.0
	Secondary	32	59.3	19	47.5
	Tertiary	1	1.9	14	35.0
	Other	1	1.9	5	12.5
Food Service Industry Experience	1 – 5 years	12	22.2	8	20.0
	6 – 12 years	5	9.3	10	25.0
	13 – 20 years	17	31.5	5	12.5
	21 – 30 years	18	33.3	11	27.5
	> 30 years	2	3.7	6	15.0
On-the-job training		22	40.7	14	35.0
Role	Cook	24	44.4	9	22.5
	Server	25	46.3	8	20.0
	Caterer	1	1.9	-	-
	Kitchen Supervisor	4	7.4	-	-
	Chief	-	-	12	30.0
	Bursar	-	-	7	17.5
	Warden	-	-	4	10.0

majority of individual respondents indicated they understood the importance of safe food handling and their personal responsibility for food safety, but respondent attitudes about proper food storage and holding temperatures and food safety were mixed (Table 2). The majority of institutional respondents reported employees washed hands properly and frequently, appeared in good health, kept fingernails short, unpolished and clean, and wore little jewelry (Table 3).

Microbiological testing of foods

A total of 48 food samples (27 from the University, 21 from restaurants outside the University) were collected (Table 4). The most commonly served foods were posho, rice, beans, and beef, and there was a larger variety of foods served in Group B facilities.

The mean APC for all food samples was 937,165 (Figure 1). There were no statistically significant differences in the mean APC for Group A (925,626 CFU/g), versus Group B samples (952,000 CFU/g). Using the APC cutpoint of 100,000 CFU/g, 66.7% of Group A facilities and 71.4% of Group B facilities served meals in violation of food safety standards. Of facilities with violations, all three samples from one facility in Group A (A3) and two facilities in Group B (B3, B4) had APCs higher than 100,000 CFU/g; and three in Group A (A5, A6, A7) and two in Group B (B1, B7) had two samples with unacceptably high APCs.

Total coliforms were found in samples from all facilities, and total coliform plate counts were significantly higher (Kruskall-Wallis $X^2 = 3.88$, 1 d.f., $p = 0.0489$) in samples from Group B (7,965.2 CFU/g) than Group A (5,271.1 CFU/g) (Figure 2). Six Group A facilities and one Group B facility had at least one sample with no total coliforms. The highest mean total coliform CFU/g was 40,490 CFU/g, from one Group A facility (A4). Using a cutpoint of 100 CFU/g, there were no statistically significant differences in the numbers of samples with unacceptable

Table 2. Individual respondent hygiene practices and attitudes (n = 54).

Parameter	Response	#	%
Employee practices			
Meat can be chopped with vegetables	Yes	14	25.9
Raw and cooked foods should be kept separate	Yes	43	79.6
	Yes	7	13.0
Defrosted foods may be frozen only once	No	33	61.0
	Not sure	14	25.9
PPE use reduces food contamination risk	Yes	50	92.6
Knowing fridge temperature reduces food contamination risk	Yes	24	44.4
	Yes	24	44.2
Checking fridge thermometer settings once a day is important	No	26	48.4
	Not sure	4	7.4
Improper heating of food causes foodborne diseases	Yes	52	96.3
Improper food storage may be hazardous to health	Yes	52	96.3
Employee attitudes			
Safe food handling is important	Yes	50	92.6
Learning more about food safety is important	Yes	51	94.4
Food preparation without hygiene rules causes foodborne diseases	Yes	50	92.6
Employee personal hygiene			
How I handle food relates to food safety	Yes	45	83.3
Do not come to work if I have flu or diarrhea	Yes	29	53.7
Do not wear jewelry during food preparation	Yes	29	53.7
Food service staff with cuts on fingers or hands shouldn't touch cooked or unwrapped foods	Yes	30	55.6

Table 3. Institutional respondent hygiene practices and attitudes (n = 40).

Parameter	# Yes	%
Employee practices		
Employees use effective hair restraints	10	25.0
Hands are washed properly and frequently	34	85.0
Employees cover wounds completely	15	37.5
Food preparation activities only in designated zones	15	37.5
Employees wear clean and proper uniforms	10	25.0
Fingernails are short, unpolished, and clean	27	67.5
Jewelry is limited to a plain ring	34	57.5
Employees use disposable tissues	4	10.0
Facilities		
Employees appear in good health	32	80.0
Sinks are unobstructed	22	55.0
Sinks are stocked with soap	10	25.0
Hand washing reminder signs are posted	6	15.0
Employee toilets are operational and clean	35	87.5

coliform levels between the two groups. Only three Group A facilities and one Group B facility had acceptable mean total coliform levels.

Isolation of *E. coli* was not common: it was detected in 6 samples from five facilities from Group A, and 7 samples from three facilities from Group B (Figure 3). The highest mean *E. coli* CFU/g (7,530 CFU/g) was found in the same Group A facility with the highest mean

Table 4. Types of foods in samples collected from study facilities

Food	Group A (n=9)		Group B (n=7)	
	# Facilities serving	# Samples	# Facilities serving	# Samples
Posho	9	26	7	15
Rice	9	25	6	13
Beans	9	13	5	8
Beef	8	8	7	10
Matooke	0	0	7	17
Cabbage	2	2	5	8
Sweet Potato	1	1	6	9
Irish Potato	1	1	3	7
Chicken	4	4	2	2
Fried Chicken	4	4	2	2
Soup	4	4	1	1
Other Foods*	0	0	7	25

*Fried rice (5 samples from 4 sites); groundnut stew (4 samples from 4 sites); greens (4 samples from 3 sites); cassava, millet (3 samples from 2 sites); pumpkin (2 samples from 2 sites); and avocado, fish, goat, spaghetti (1 sample from 1 site).

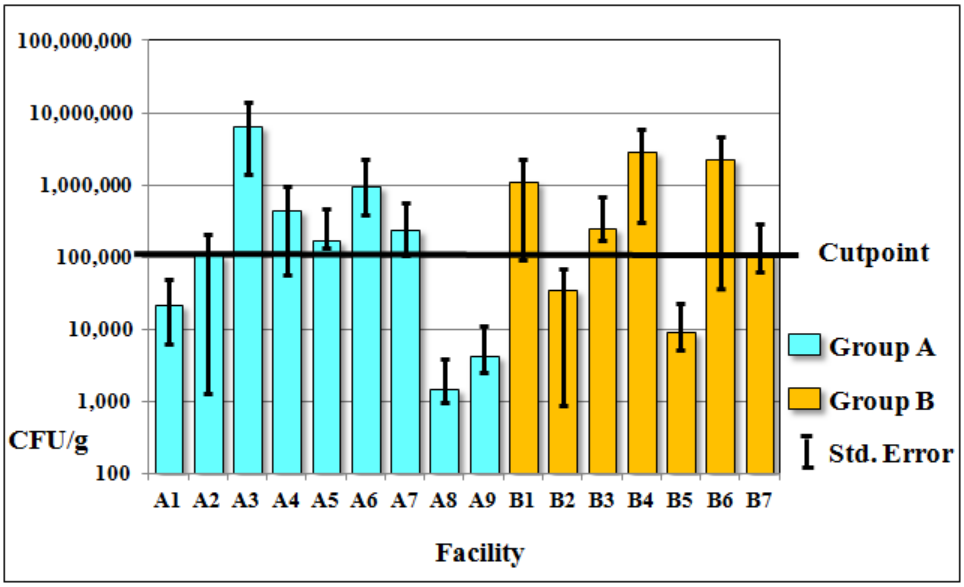

Figure 1. Mean Aerobic Plate Counts for food samples from university residence halls (n=9) and local restaurants (n=7), with cutpoints for microbiological food safety.

total coliforms (A4). Again, using the 100 CFU/g cutpoint for food safety, only one Group A and two Group B facilities had unacceptable levels of *E. coli.* There were no statistically significant differences in *E. coli* levels between the two sites.

Two food samples from two Group A facilities (A2, A9), collected on the second sampling visits, were positive for *Salmonella*. Both halls served the same food items (boiled rice, posho and beans) on that date. Facility A2 had APC (104,433 CFU/g) and total coliforms (107 CFU/g) slightly above the food safety cutpoints, while facility A9 had an acceptable APC (4,200 CFU/g) but unacceptably high total coliforms (1,007 CFU/g). Both facilities had no *E. coli*.

When examining specific foods, there were several foods that were associated with increasing or decreasing the risk of unacceptable levels of bacteria (Table 5). Food samples from both groups that contained beef were at

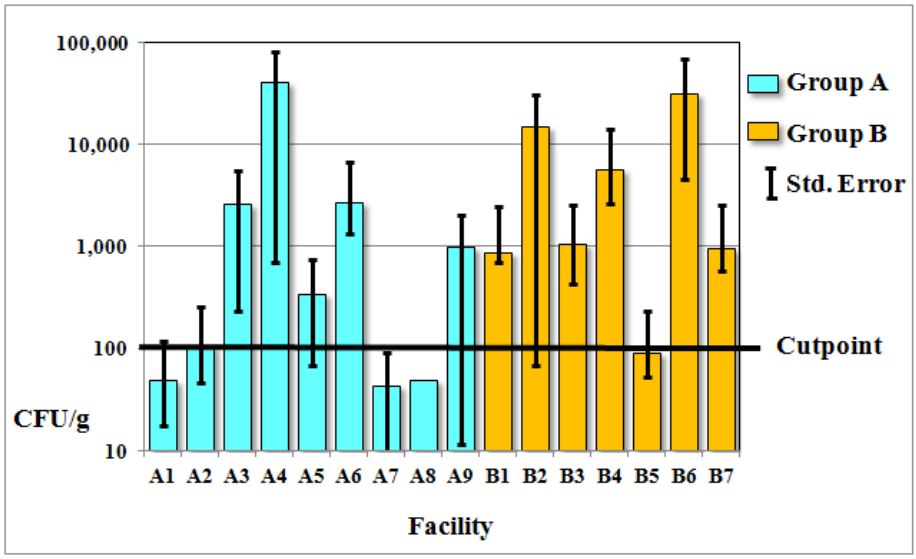

Figure 2. Mean total coliform counts for food samples from university residence halls (n=9) and local restaurants (n=7), with cutpoints for microbiological food safety.

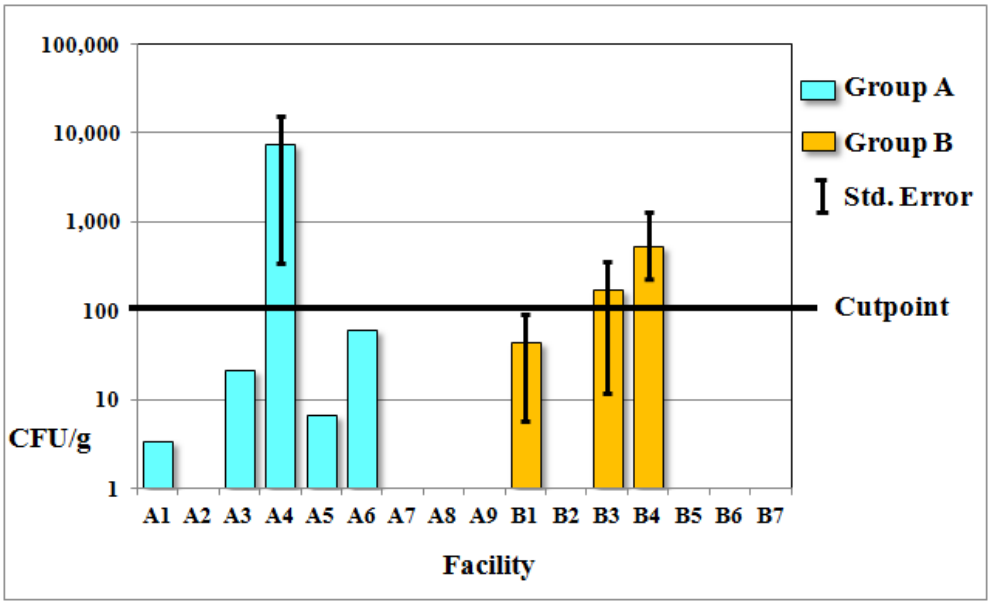

Figure 3. Mean *E. coli* counts for food samples from university residence halls (n=9) and local restaurants (n=7), with cutpoints for microbiological food safety.

higher risk for unacceptable coliform levels, and mean coliform counts for samples with beef (13,117 CFU/g) were significantly higher (Kruskall-Wallis X^2 – 4.5, 1 d.f., p = 0.0345) than samples that did not contain beef (2,449 CFU/g). Samples from Group B facilities that contained beans were at higher risk for unacceptable levels of *E. coli*, and had significantly higher mean *E. coli* (217.5 CFU/g) than meals that did not contain beans (29.2 CFU/g) (Kruskall-Wallis X^2 = 4.8, 1.d.f., p = 0.0278). Meals that contained sweet potato were at lower risk for unacceptable APC levels for both groups combined, and this association was statistically significant when considering samples from Group B alone (89,056 CFU/g with sweet potato versus 1,605,968 CFU/g without; Kruskall-Wallis X^2 = 5.9, 1.d.f., p = 0.0156). Samples from Group B that contained matooke had statistically lower mean levels of *E. coli* than samples without matooke (37.1 CFU/g and 405.0 CFU/g, respectively;

Table 5. Associations ($p < 0.1$) between food type and unsafe levels of aerobic mesophilic bacteria, coliforms, and *E.coli*

Group	Food	# Tested	Bacteria	% Unsafe	Odds Ratio	95% C.I.
Both Groups	Posho	41	*E. coli*	12.2	0.24	0.04 – 1.46
	Beef	18	Coliforms	37.5	3.91	0.91 – 16.82
	Sweet potato	10	APC	20.0	0.10	0.02 – 0.63
	Chicken	12	Coliforms	41.7	0.29	0.07 – 1.17
Group B	Beans*	8	*E. coli*	50.0	12.00	1.02 – 14.34
	Beef	10	APC	80.0	7.00	0.97 – 50.57
	Matooke*	17	*E. coli*	11.8	0.04	0.003 – 0.66
	Sweet potato*	9	APC	22.2	0.06	0.01 – 0.51

* Association significant at $p \leq 0.05$

Kruskall-Wallis $X^2 = 5.3$, 1.d.f., $p = 0.0218$), and were significantly less likely to have unacceptable levels of *E. coli*.

Institutional and individual-level food safety attitudes and practices

A minority of institutional respondents were classified as using safe food hygiene practices (26.9% from Group A; 42.9% from Group B). There were no significant differences in age and work experience, but respondents with secondary and higher level educations were more likely to use safe food hygiene practices (O.R. = 4.75; 95% C.I. = 2.57 – 8.79). For specific practices, the use of effective hair restraints (O.R. = 56.0; 95% C.I. = 6.78 – 462.64) and posting hand washing reminder signs (O.R. = 9.33; 95% C.I. = 1.38 – 63.20) were positively associated with safe hygiene practices.

Over 90% of the 54 individual respondents (95.1% in Group A; 84.6% in Group B) were classified as using safe food handling practices. There were no significant differences in age, education, work experience, position in kitchen, or facility between safe and unsafe food handling respondents. For specific hygiene practices and attitudes, there were significant differences between safe and unsafe handling groups for wearing jewelry during food preparation (OR = 0.84, 95% C.I. = 0.71 – 1.0), and believing that food preparation without hygiene rules causes foodborne diseases (OR = 24.0, 95% C.I. = 2.14 – 269.12).

The association between individual worker risk factors and food classified as safe through microbiological analyses were tested, and odds ratios computed for nine variables were considered for inclusion in multivariable analyses (Table 6). After multivariable model building was completed, the final model for safe food (based on microbiological testing) contained only one variable: not wearing jewelry was associated with decreasing risk for unsafe foods (adjusted OR = 0.05, 95% CI: 0.00 – 1.05). Overall, 48.6% of the variation in safety of food served in Makerere University halls of residence and neighborhood restaurants was correctly explained by the model (Hosmer and Lemeshow goodness-of-fit $X^2 = 4.45$, 5 d.f., $p = 0.49$).

DISCUSSION

Food service employees

The majority of individual respondents in this study were female. Although this study found no associations between gender and safe food handling, female workers had better hygiene scores and practices than males (Çakiroğlu and Uçar, 2008; Kibret and Abera, 2012), and female clients in a study of food service outlets in Nigeria were more likely to patronize outlets with better hygiene levels (Olumakaiye and Bakare, 2013). Most respondents were from 18 to 45 years of age, and had worked in food service facilities for more than five years. Other studies have found that older workers had better hygiene scores than younger workers (Çakiroğlu and Uçar, 2008; Olumakaiye and Bakare, 2013), and workers with more than seven years of food service work experience had better hygiene scores than younger and newer workers(Çakiroğlu and Uçar, 2008).

There were differences in level of education between individual food service workers and institutional respondents. The majority (59.3%) of individual workers possessed secondary level educations, which is higher than reported in studies of food handlers (Baş et al., 2006) The majority of institutional respondents had attained higher education levels than the individual respondents. Higher levels of education have been associated with better food safety knowledge awareness, and better sanitary conditions in other studies (Zeru and Kumie, 2007; Olumakaiye and Bakare, 2013; Onyeneho and Hedberg, 2013), and a study of the environmental hygiene of food service outlets were significantly

Table 6. Association between risk factors and food safety determined by microbiological testing, from 41 workers in 9 kitchens from Makerere University, and 13 workers in 7 kitchens from local restaurants.

Variable	Level	Odds Ratio	95% C.I.
Education Level	Primary and Below	4.75*	2.57 – 8.79
	Secondary and above	(baseline)	
Use effective hair restraints	No	56.0**	6.78 – 462.64
	Yes	(baseline)	
Clean, short, unpolished fingernails	No	6.0	0.67 – 53.68
	Yes	(baseline)	
Wear jewelry during food preparation	No	0.84*	0.71 – 1.00
	Yes	(baseline)	
Cuts and abrasions covered	No	0.86	0.18 – 4.04
	Yes	(baseline)	
Hand washing reminders	No	9.33	1.38 – 63.20
	Yes	(baseline)	
Personal protective equipment reduces food contamination risk	No	1.08	1.00 – 1.18
	Yes	(baseline)	
Prepare food when sick	No	3.82	0.37 – 39.28
	Yes	(baseline)	
Prepare food disregarding hygiene rules	No	24.0**	2.14 – 269.11
	Yes	(baseline)	

*p < 0.05; **p < 0.01

associated with the age, education level and income of operators (Olumankaiye and Bakare, 2013). The requirements for employee education and training by food service facilities has been shown to have positive influences on food hygiene. Studies have reported that food service workers from hospitals and schools had better food safety knowledge, attitudes and practice scores than workers from smaller food service establishments, fast-food outlets, and vending stalls or street food vendors (Baş et al., 2006; Onyeneho and Hedberg, 2013).

Specific training for food service workers was not common in this study. Only 40.7% of individual respondents and 35% of institutional respondents had attended any on-the-job training since they joined employment, which is lower but comparable to other studies (47.8%, Baş et al., 2006). In several studies, food service workers that received training had better hygiene scores and safe food handling practices than those that did not receive training (Baş et al., 2006; Kibret and Abera, 2012; Onyeneho and Hedberg, 2013; Ababio and Lovatt, 2014). This indicates that on-the-job and short term training sessions for food service workers would be beneficial to facilities in this study. A study of 277 food handlers in Ethiopia found the most common sources of information about food safety were mass media (50%) and health centers (42.7%) (Zeru and Kumie, 2007), which also suggests that using less traditional venues for education, such as radio or newspaper campaigns, can also provide useful information to food service workers and the population in general.

Food service employee knowledge, attitudes, and practices

The majority of individual respondents indicated they understood the importance of safe food handling and their personal responsibility for food safety, but knowledge and attitudes about some aspects of food safety were mixed. The majority of individual respondents acknowledge the importance of separating raw and cooked food, using personal protective equipment (PPE) to reduce food contamination, and the hazards of improper food heating and food storage, which has been seen in other studies of food service workers (Baş et al., 2006). However, less than 45% of respondents indicated that knowing refrigerator temperatures was important, and that checking refrigerator thermometer settings was important, which was seen in 35% of head chefs and managers of restaurants in Nigeria (Onyeneho and Hedberg, 2013).

Over 80% of individual respondents reported that food handling affected food safety, but only 54% of respondents understood that working when sick or wearing jewelry during food preparation were practices to be avoided for food safety. Approximately 44% of respondents did not acknowledge that food service workers with cuts on their fingers or hands should avoid

handling cooked or unwrapped foods, which is similar to findings from other studies in Turkey and Nigeria (Baş et al., 2006; Onyeneho and Hedberg, 2013). One study reported that 47% of food service chefs and managers had a lack of awareness that sick persons can spread foodborne illness (Onyeneho and Hedberg, 2013), and surveys of food vendors found that only 42% of workers in Nigeria (Olowogbon et al., 2012) and 23% in Ethiopia (Zeru and Kumie, 2007) had at least one medical examination per year. The health status of these workers could have serious implications for food safety.

Environmental hygiene is important for food safety, and necessary to support safe food handling and hygiene by employees. It was the duty of the employer to provide and enforce use of facilities and tools for the safe handling of food, including PPE. The majority of institutional respondents reported employees washed hands properly and frequently, appeared in good health, kept fingernails short, unpolished and clean, and wore little jewelry, but this study revealed inadequate provision of uniforms, hygiene and food handling equipment. Most facilities had sinks with no soap, hand washing reminder signs were not posted, and kitchen staff did not wear proper or full uniforms (including hair restraints or a cap). In sites with poor access to clean running water, hand washing water (Taulo et al., 2009) and dish washing water (Nkere et al., 2011) can harbor fecal bacteria and serve as a source of bacterial contaminants for both food and workers. Other studies have found that foods that have been properly prepared can become contaminated by serving utensils washed in contaminated water, or handled by unwashed hands (Taulo et al., 2009; Nkere et al., 2011).

From the results of the multivariable analysis, food service employees who wore jewelry (36% of employees) during food preparation were more likely to be associated with the serving of unsafe food. It is possible that, when jewelry becomes contaminated, the lack of soap at sinks and absence of hand washing reminder signs allows jewelry to stay contaminated for longer periods of time, and increase the opportunities for cross- contamination during food handling. It is also likely that the insistence on wearing large amounts of jewelry during food preparation is reflective of a lack of awareness of potential hazards: workers may not realize that this can be a source of contamination, or may not be aware of the hazards that avoiding hand washing to avoid damaging jewelry can pose.

Although the majority of individual respondents indicated they understood the importance of safe food handling and their personal responsibility for food safety, they performed poorly in important food safety and hygiene practices, which has been widely reported in food hygiene practice studies in Ghana (Ababio and Lovatt, 2014), Nigeria (Ondyeneho and Hedberg, 2013), and other countries (Fulham and Mullan, 2011). In one study of the "intention-behavior gap" in hygienic food handling (Fulham and Mullan, 2011), researchers found that subjective norms (food handling practices by co-workers, "peer pressure") and perceived behavioral control (the worker's perception of the ease or difficulty of performing the behavior) predicted their intentions to follow good food handling practices and these intentions predicted behavior. However, the study found that behavioral prepotency (old habits, past behaviors) was the best predictor of intention and behavior, regardless of worker knowledge or attitude (Fulham and Mullan, 2011). Hygienic food handling has immediate negative perceived behavioral control (takes more time, costs more, inconvenient to use, uncomfortable to wear), and the benefits of hygienic food handling are not immediate and personal, but are more long-term and general, which contributes to why workers often fail to use best practices even when they are aware of their importance. Some possible solutions to overcome the "intention-behavior" gap are to change the working atmosphere of food service workers (subjective norms) or to change the perceptions of the ease or difficulty of using safe food handling practices (perceived behavioral controls). Individual respondents in this study indicated their willingness to wear proper uniforms and use hair restraints if the employer provided them.

Safety of food served in residence halls and neighborhood restaurants

The majority of food samples tested in this study had APC and total coliform CFU/g counts higher than acceptable, which indicates that there are ample areas for improvement in safe food handling. In the case of the samples that tested positive for *Salmonella*, both came from two halls that served the same food items on that sampling date, and were collected by different individuals. This suggests a common source of *Salmonella* for these two food service facilities, but identifying the common source is difficult, given that the two halls are far apart and unlikely to share personnel or facilities.

The findings that there were significantly higher levels of coliforms in samples from neighborhood restaurants (Group B) than in samples from University food service facilities (Group A) were expected, given that the residence halls have better facilities than the restaurants, of which some operate in improvised structures. However, the lack of significant differences in APC or *E. coli* CFU/g in food samples from Makerere University food service facilities (A1-A9) than in food samples from neighborhood restaurants (B1-B7) was unexpected. This may be explained by laxity in supervision in the halls as compared to the restaurants, where the owners seem to supervise their staff more keenly. However, given the generally low levels of good hygiene practices and problems in environmental hygiene, there are likely other factors beyond the scope of this study which influenced

the levels of bacteria found in food samples from food service facilities in this study.

Conclusions

In general, this study has found that there is a critical need for improving food safety at restaurants and dining halls at Makerere University. The APC levels in samples of all facilities were higher than desired. The finding that the majority of respondents did not follow good hygiene practices (e.g., use of hair restraints), indicates laxity or lack of supervision, and a need to overcome the problems of the "intention-behavior gap" in hygienic food handling. Employees in food service facilities are aware of proper food handling hygiene practices and have positive attitudes towards food safety, but inadequate facilitation (e.g., lack of soap at sinks) prevents them from observing good hygiene practices when handling food.

Based on results from this study, there are specific areas for improvement in both university dining halls and local restaurants. For individual kitchen workers, providing training on personal hygiene and proper food handling techniques will be helpful, particularly in raising awareness of some specific practices (for example working while sick, handling food when there are cuts or wounds on the hand).

At the institutional level, food service facility managers should improve environmental hygiene, including steps such as ensuring that sinks or hand washing basins in kitchens and toilets have running water, and are stocked with soap at all times, and hand washing reminder signs should be posted. To improve the workforce itself, food service facility managers should establish and maintain minimum qualifications for employees above primary education, as better-educated staff are more likely to adhere to good hygienic practices. Managers can support safe food handling by their employees by providing and enforcing wearing of uniforms, including clothing, hair restraints, aprons and gum boots, by all food service workers.

There is a need for governmental support to improve food safety management systems, and education and awareness programs (Onyeneho and Hedberg, 2013; Ababio and Lovatt, 2014). Regular inspection of food service facilities is critical: facilities subject to regular inspection had better sanitary conditions than unin-spected facilities (Zeru and Kumie, 2007). Finally, government and leaders in the food service industry should strive to institute a thorough assessment of the food processing chain to identify and address areas that are responsible for food contamination.

Conflict of interests

The authors did not declare any conflict of interest.

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