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Determining Slice Thickness of Banana (*Musa* spp.) for Enclosed Solar Drying using Solar Cabinet Dryer under Ethiopian Condition

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ABSTRACT

The present study was executed to determine optimum thickness of banana slice for enclosed solar drying and to evaluate the Natural Resource Institute (NRI)-modified local Kawanda solar cabinet dryer under Ethiopian condition. In this study, six slice thicknesses of banana and NRI-modified solar cabinet dryer were evaluated from 2006 to 2007. The percentages of sticked, mouldy, brown and shriveled slices and moisture content and percentage of acceptable slices were determined after four days of drying. The results indicated that the percentages of sticked, shriveled and brown slices decreased whereas the moisture content increased as the slice thicknesses increased. Percentage of mouldy slices was higher at 6 mm (38%) whereas no mouldy slices were observed at slice thicknesses of 1 to 4 mm and vey few (3%) mouldy slices at 5 mm. Moisture contents of less than 20% were achieved after four days of drying at all slice thicknesses except at 5 and 6 mm. Large percentages of acceptable slices were obtained at 3 and 4 mm thicknesses. From these results, banana slice thicknesses of 3 and 4 mm were selected as optimal for enclosed solar drying. The dryer was confirmed to be suitable for Ethiopian condition. However, it is expensive and not handy for small-scale households. Hence, we reduced the size of the dryer three times. Therefore, we suggest the use of NRI-modified rural Kawanda solar cabinet dryer for medium-scale drying whereas the JUCAVM-modified dryer for small-scale households using banana slice thickenesses of 3 and 4 mm. We suggest the need for further studies to investigate the physico-chemical characteristics of the dried banana product.

Key words: Banana, *Musa* spp., slice thickness, solar cabinet dryer, solar drying

INTRODUCTION

Banana (*Musa* spp.) is among the major tropical fruits that are becoming more important food items at both producer and non-producer countries. Bananas play a vital role in the diets of humans. Accordingly, the dietary value per 100 g of dried powder or flakes of banana include 70% water, 23% carbohydrate, 1.2% protein, 0.2% fat, 2.6% crude fiber, 3% others and 88 calories (Elkhoreiby, 2003). In Ethiopia, it is one of the widely produced and used tropical fruits. The area harvested and the total annual production of banana in the year 2000 were 15,000 ha and 100,000 Mg whereas increased to 39, 428 ha and 260,000 Mg, respectively in 2008. Most of the banana produced in Ethiopia is consumed locally with only a few exported to Djibouti. The volume of export has increased from 497 Mg in 2000 to 2574 Mg in the year 2007. However, global share of Ethiopia in banana export was only about 0.02% in the year 2007 (FAO, 2010).

Fresh banana fruits are highly perishable and bulky (Taiwo and Adeyemi, 2009). Consequently, their transportation to distant places is costly and their condition on arrival in the importing country may be less than satisfactory. The difficulties with short storage life of bananas are worsened by the poor transport and marketing system in developing countries like Ethiopia. Banana has an average storage life of 7 to 28 days under optimum storage temperature of 14°C (Chia and Huggins, 2003). Extent of postharvest loss of banana at retail level in Jimma town was 95% (personal communication with retailers). These losses could be due to the perishable nature of the produce, poor postharvest handling and marketing conditions and lack of cheap and appropriate postharvest technology. Hence, much effort is needed in the area of generating efficient, low-cost, indigenous technology that minimizes postharvest loss of banana fruits. One of these methods is to increase local value-added food products through the development of micro- and small-scale agro-industries. Solar drying of fruits is one of these technologies, which can enhance the shelf life of fruits. Besides, it improves nutritional standards in diets, minimize seasonal gluts and reduce transportation cost. It also resolves the problems of high prices and shortages of fossil fuels by using alternative renewable energy sources (Janjai *et al*., 2008).

Traditionally, bananas are dried in an open sun. Compared with drying in the sun, solar dryers can generate higher air temperatures and lower relative humidity (Brett *et al*., 1996b). This results in shorter drying times and lower product moisture contents and reduced spoilage during the drying process and in subsequent storage. The higher temperatures attained in solar drying also act as a deterrent to insect and microbial infestation. Protection of the drying fruit against rain, dust, insects and other pests is also improved when drying in an enclosed structure compared to open sun drying. All of these factors contribute to improving quality and providing a more consistent product (Brett *et al*., 1996b; Bala, 1998; Smitabhindu *et al*., 2008).

Currently, bananas are dried world wide using various types of solar dryers (Brett *et al*., 1996a). However, simple drying techniques are often the most appropriate for application in rural farming areas like Ethiopia that have limited technical, financial and managerial resources (Brett *et al*., 1996b). In Ethiopia, though traditional drying is commonly used for other crops, little attempts have been made so far for drying of fruits in general and solar drying of bananas in particular. However, Ethiopia has favourable conditions for the solar drying of banana including among others increased banana production (FAO, 2010) and sufficient sunshine (Hassanain, 2009). In order to efficiently utilize these potential and minimize the postharvest loss of banana and increase its availability through out the year while maintaining quality, Ethiopian small-scale farmers need low-cost and efficient solar dryer.

Though there are many designs of solar dryers world-wide, experimental and technical evaluations carried out in Uganda have shown a Natural Resources Institute (NRI)-modified version of the local Kawanda cabinet dryer to be well suited for local conditions (Brett *et al*., 1996a). It has the capacity to dry 25 to 30 kg fruit within four days. So far, this dryer was not evaluated in Ethiopia. Bananas are sliced before drying and the optimal slice thickness for proper drying for best quality has to be determined. In Uganda, the suggested thickness for banana slice was 5 mm (Brett *et al*., 1996b). However, appropriate slice thickness of banana has not yet been determined in Ethiopia. In order to utilize this solar dryer in Ethiopia, determining optimal thickness of banana slices is necessary. Besides, it is essential to evaluate the NRI-modified local Kawanda solar cabinet dryer under Ethiopian condition. Therefore, the current research was initiated to determine optimum thickness of banana slice for enclosed solar drying and to evaluate NRI-modified local Kawanda solar cabinet dryer under Ethiopian condition.

MATERIALS AND METHODS

Description of the study area: The research was executed at Jimma University College of Agriculture and Veterinary Medicine (JUCAVM) for two years (2006 to 2007) from December to February. JUCAVM is located at about 7°, 33' N Latitude and 36°, 57' E Longitude at an altitude of 1710 meters above sea level. The mean minimum and maximum temperatures are 11.8 and 27.9°C, respectively. The mean minimum and maximum relative humidities are 31.2 and 91.4%, respectively. The mean annual rainfall of the area is 1500 mm. The mean monthly minimum and maximum temperatures of Jimma area were obtained from National Meteorological Agency (NMA, 2010; Fig. 1a). December, January and February are there dry months for Jimma area

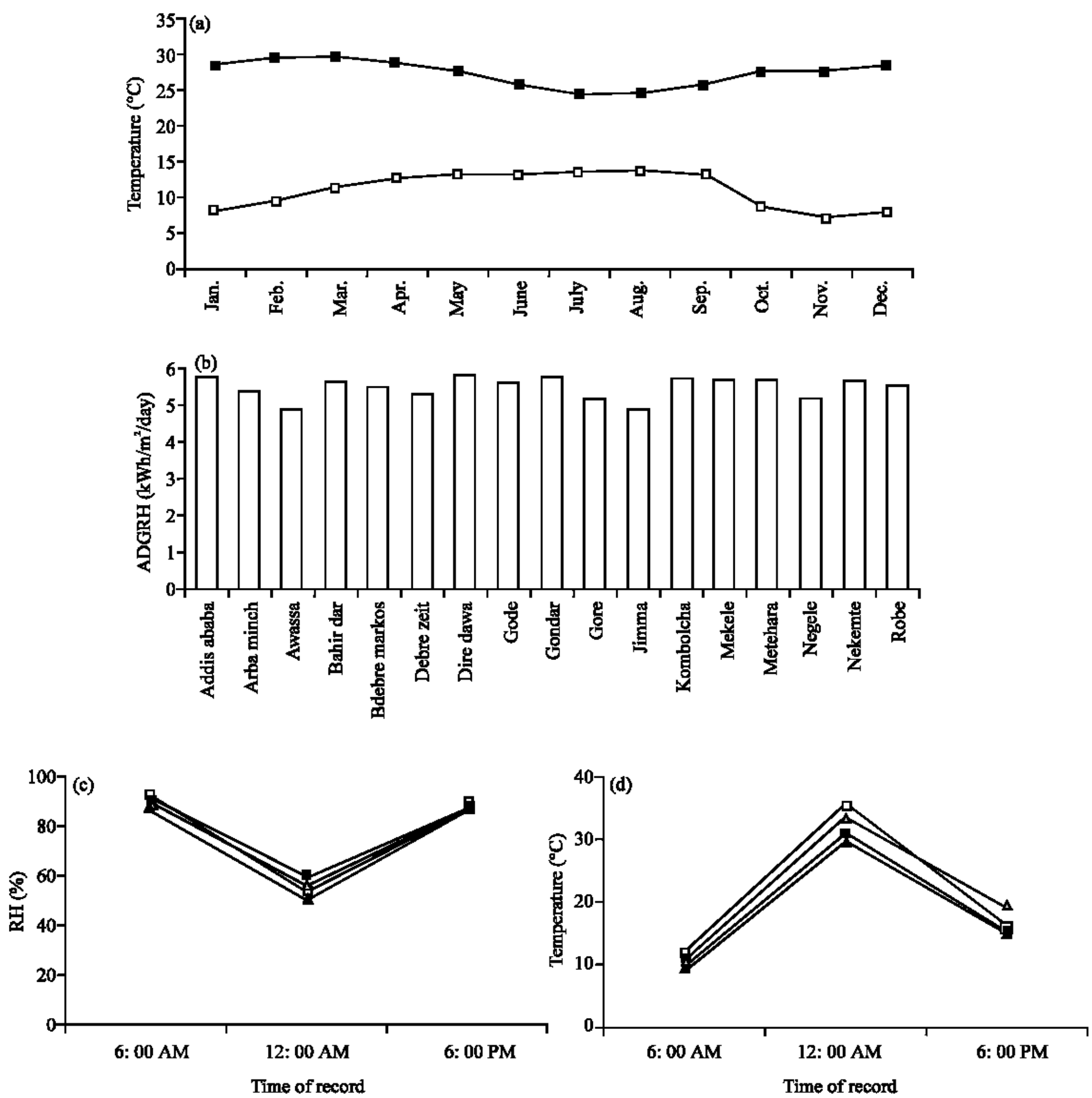

Fig. 1: (a) The mean monthly minimum (□) and maximum (■) temperatures of Jimma area; (b) yearly average daily global radiation on the horizontal surface (ADGRH in $kWh/m^2/day$) estimations by NASA for some locations in Ethiopia (c) and relative humidity (RH and (d) temperature recorded inside the drying chamber during the experiment period: □ Y1S1 (year 1 experiment set 1), ■ Y1S2 (year 1 experiment set 2), △ (year 2 experiment set 1) and ▲ (year 2 experiment set 2)

(NMA, 2010). The average daily global radiation on the horizontal surface (ADGRH in kWh/m^2/day) as estimated by NASA for some locations in Ethiopia confirmed the potential for solar drying in the country (Fig. 1b; EREDPC, 2007). During the experiment periods, data on relative humidity (Fig. 1c) and temperature (Fig. 1d) were recorded three times per day inside the drying chamber (6:00 AM, 12:00 AM and 6:00 PM).

Description of the solar dryer: The dryer used for this experiment was the NRI-modified local Kawanda cabinet solar dryer (Brett *et al*., 1996a). The dryer consisted of a main frame with eight supporting legs, incorporating the drying chamber covered with transparent polyethylene sheet. The drying chamber was 4.4 m long ×1.5 m deep ×0.8 m high overall and contains 12 trays to provide a total drying area of 10 m^2. The dryer was constructed mainly from 5×5 cm softwood. However, the drying trays, rails and support bars were made from 5×2.54 cm hardwood to provide the strength and the durability needed. The front of the chamber has three hinged doors to provide access for loading and unloading the trays used for drying. There are two layers of trays one above the other were each layer can accommodate six trays and these are supported on wooden rails. The trays consist of a hardwood frame across which is stapled plastic mosquito mesh onto which will be placed the slices of banana for drying (Brett *et al*., 1996a; Fig. 2).

Slice preparation and drying: Banana fruits were directly purchased at full maturity from growers around Mizan, southwestern Ethiopia. Unripe fruits were allowed to ripen uniformly before being processed. Fruits of uniform diameter and ripeness were selected and used for slice preparation (Brett *et al*., 1996b). The experiment was laid-out in Randomized Complete Block Design (RCBD) with six treatments and four replications. The treatments were 1, 2, 3, 4, 5 and 6 mm banana slice thicknesses. Each tray was divided into four equal parts and each part randomly holds one treatment. Therefore, there were 24 parts to hold six treatments replicated four times. Twenty-five slices were used per treatment in each replication. The slices were arranged on the trays carefully to avoid overlapping (Brett *et al*., 1996b). The trays were loaded into the cabinet, sliding them cautiously in on the runners. The doors were closed promptly after each tray is loaded and remain closed until the next tray is brought so as to hasten drying (Brett *et al*., 1996b). Four days after dryer loading, the slices were unloaded (Fig. 3) and observations were performed. The experiments were executed in 2006 and 2007 for two years with two runs per year totaling to four runs.

Fig. 2: NRI-modified local kawanda cabinet solar dryer constructed at JUCAVM (Brett *et al*., 1996a)

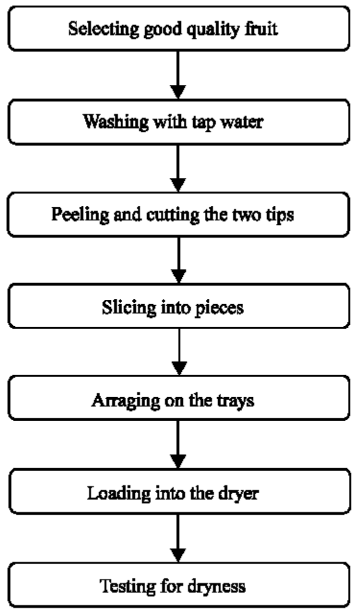

Fig. 3: Banana slice preparation and drying procedure (modified from Brett *et al.*, 1996b)

Fig. 4: Reference cards used for checking dried fruit quality. (a) Unacceptable: too light, fruit under-ripe and starchy, cardboard-like texture; (b) acceptable: good quality, no dusty appearance, pliable, chewy, natural aroma and (c) unacceptable: too dark and with blackening, fruit over-ripe and/or too long in the dryer (Brett *et al.*, 1996b)

Observations: Slices per treatment were weighed before and after drying and drying ratio was determined. After four days of drying, the numbers of sticked, brown and shriveled slices were counted and percentages were determined. Numbers of slices on which mould developed after four days of drying and the subsequent storing in polyethylene bag for a week were counted and percentage was determined. Moisture content of the dried product was tested with moisture tester after four days of drying. The dried products were compared with reference cards (Fig. 4) to determine the percentage of acceptable slices (Brett *et al.*, 1996b).

The dryer was evaluated for its handiness and cost for use by small-scale households. To evaluate handiness, the number of persons required to carry were assessed. Regarding the cost, the actual cost of the dryer was considered whether it is affordable by a household.

Statistical analysis: The data from the four sets were evaluated and no differences were observed and as a result an average data from the four runs was used for analysis to increase the robustness. The assumptions were checked and the data were subjected to analysis of variance with GenStat computer software, GenStat for Windows 12th Edition (VSN International, 2009). Differences between significant treatment means were compared using Fisher's Protected Least Significant Difference (LSD) test.

RESULTS AND DISCUSSION

Determination of slice thickness: There were highly significant ($p<0.001$) differences among the mean slice thicknesses for all the response variables tested except drying ratio. The effect of slice thickness on drying ratio was not significant (data not shown). For percentage of sticked slices, a highly significant effect of slice thickness was observed ($p<0.001$). Percentages of sticked slices decreased with an increase in slice thickness. As a result, none of the slices were sticked to the drying tray at 4, 5 and 6 mm slice thicknesses whereas more than 60% of the slices with 1 and 2 mm slice thickness were sticked to the drying tray (Fig. 5a). Slices with 1 and 2 mm thickness easily damaged while removing from the tray. At 3-mm thickness, less than 40% of the slices were sticked to the tray and those, which sticked to the try also easily removed without damage. This is in line

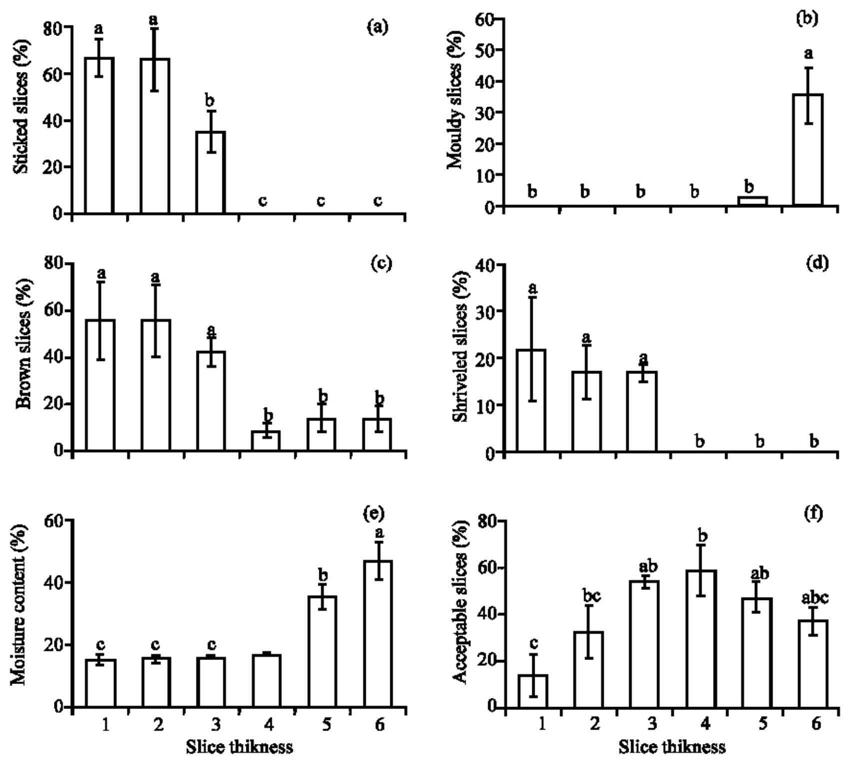

Fig. 5: (a) Influences of banana slice thickness on the percentage of sticked (LSD = 22.85); (b) mouldy (LSD = 12.2); (c) brown (LSD = 28.26); (d) shriveled (LSD = 13.72); (e) moisture content of (LSD = 9.28) and (f) acceptable (LSD = 25.88) slices four days after drying in NRI-modified enclosed solar dryer under Ethiopian condition. Percentages of mouldy slices were determined after two weeks of storage under room temperature following four days of drying. Means followed by different letters differ significantly ($p<0.05$) as established by Fisher's protected LSD-test. Vertical bars represent mean values±SE

with previous reports that indicated very thin pieces tend to stick to the drying trays and will be difficult to remove (Brett *et al.*, 1996b).

A significant effect of slice thickness was observed for percentage of mouldy slices, ($p<0.001$; Fig. 5b). The percentage of mouldy slices was higher at 6 mm (38%) whereas no mouldy slices were observed at slice thicknesses of 1, 2, 3 and 4 mm few at 5 mm thickness (3%). The thicker the slice, the higher the moisture retained and hence the higher the chance for mould development and the shorter the shelf life of the product. On the other hand, the thinner the slice the faster the drying rate and the lower the moisture content and as a result the water activity of the material considerably decreased and the microbiological activity reduced (Doymaz, 2008). This could be the probable reason for the absence of mouldy slices at slice thicknesses of 1 to 4 mm thickness and very low at 5 mm (3%) in our present study.

Figure 5 influences of banana slice thickness on the percentage of sticked (a; LSD = 22.85), mouldy (b; LSD = 12.2), brown (c; LSD = 28.26), shriveled (d; LSD = 13.72), moisture content of (e; LSD = 9.28) and acceptable (f; LSD = 25.88) slices four days after drying in NRI-modified enclosed solar dryer under Ethiopian condition. Percentages of mouldy slices were determined after two weeks of storage under room temperature following four days of drying. Means followed by different letters differ significantly ($p<5\%$) as established by Fisher's protected LSD-test. Vertical bars represent mean values ±SE.

For percentage of brown slices, a highly significant effect of slice thickness was observed ($p = 0.005$; Fig. 5c). As the slice thickness increased, the percentages of slices that are brown increased. As a result, the lowest percentage of brown slices was obtained at 4 mm though followed by 5 and 6 mm thicknesses. This higher brown slice percentage in the case of thinner slices could be due to over drying due to faster drying rate that resulted in the formation of brown pigments (Barreiro *et al.*, 1997; Lopez *et al.*, 1997; Maskan 2001; Prachayawarakorn *et al.*, 2008).

A highly significant effect of slice thickness was observed for percentage of shriveled slices, ($p = 0.007$; Fig. 5d). The number of shriveled slices decreased as the slice thickness increased. Consequently, no shriveled sliced were observed at 4, 5 and 6 mm slice thicknesses. Migration of large volume of moisture and transfer of heat in thinner slices lead to many physical changes including cell wall collapse and shrinkage of the slices. This is in agreement with previous reports (Lozano *et al.*, 1983; Mayor and Sereno, 2004; Panyawong and Devahastin, 2007; Tsami and Katsioti, 2000; Prachayawarakorn *et al.*, 2008). Such shriveling is detrimental to the textural properties of the product (Prachayawarakorn *et al.*, 2008). Thinner slices dry at faster rate and as a result the higher the percentage of shriveled slices. Several studies indicated that higher drying rates result in higher degrees of deformation of dried products (Li *et al.*, 1999; Markowski *et al.*, 2003; Prachayawarakorn *et al.*, 2008).

A highly significant effect of slice thickness was observed for moisture content of slices ($p<0.001$; Fig. 5e). The moisture content was significantly higher at 6 mm slice thickness. Moisture contents of less than 20% were obtained after four days of drying at all slice thicknesses except 5 and 6 mm. The thicker the slice, the slower the drying rate and hence more water was retained after 4 days of drying. Our current finding is in agreement with observations on leek (Doymaz, 2008), egg plant (Ertekin and Yaldiz, 2004), apples (Roman *et al.*, 1979; Wang and Chao, 2002; Sacilik and Elicin, 2006), grape leather (Maskan *et al.*, 2002) and potato slices (Akpinar *et al.*, 2003). Thinly-sliced bananas dried faster and hence lower moisture content was observed due to the reduced distance the moisture travels and increased surface area for a given volume of the samples (Ramesh, 2003).

Thicker slices however had higher moisture content and as a result have short shelf life due to mould development and other sources of spoilage. If they are not sufficiently dry, they will become mouldy and completely unsalable in a short time (Brett *et al.*, 1996b). Banana is commercially dried to less than 20% final moisture content (Bowrey *et al.*, 1980; Robinson, 1980), or down to 14 to 15% (Garcia *et al.*, 1988) or even to 10% (on dry basis) (Brett *et al.*, 1996b). At such moisture content level, dried banana can be stored for at least 6 months (Robinson, 1980).

For percentage of acceptable slices, a highly significant effect of slice thickness was observed ($p = 0.023$; Fig. 5f). Large numbers of acceptable slices were obtained at 4 mm thickness though not significantly different from 3 and 5 mm thickness. This was also in agreement with other response variables. The thinner the slice, the higher the chance of over-drying and hence sticking to the drying tray, shriveled and become brown and hence unacceptable. On the other hand, the thicker the slice, the higher the moisture content beyond the optimal range and the greater the chance of mould development and hence the product becomes unacceptable. Furthermore, thicker slices had higher moisture content and as a result have short shelf life, which is also unacceptable. The fruit may be sufficiently dry if it is not possible to squeeze out moisture from the slices, the middle is no longer moist if tearing a piece in half and slices are pliable, but do not stick together (Brett *et al.*, 1996b).

Correlation between response variables: We have analyzed the correlation between the response variables and found that clear trends were observed though not significant in most of them. However, strong correlations were observed between percentage of shriveled and brown slices ($R^2 = 0.7$; Fig. 6a) and between moisture content and percentage of mouldy slices ($R^2 = 0.5$; Fig. 6b). There is an increase in the percentage of brown slices with increase in percentage of sticked slices, both related to over drying which was the case of thinner slices (Fig. 6a). At slice thicknesses of 1 to 4 mm where moisture contents of less than 20% were observed, no mouldy slices were observed and then, the percentage of mouldy slices increased with an increase in moisture content (Fig. 6b).

Though not significant, there were trends between different response variables and the percentage of acceptable slices (Fig. 7). At slice thicknesses 6, 5 and 4 mm, the percentages of sticked slices were zero whereas the percentages of acceptable slices were 37, 47 and 58%, respectively. Then, as the number of slice thickness decreased from 4 to 1 mm, the percentage of sticked slices increased from 0 to 67% whereas the percentage of acceptable slices decreased from 58 to 13% (Fig. 7a). This showed that the percentages of acceptable slices were higher at slice thicknesses of 3 and 4 mm where the percentages of sticked slices were less than 40%. At slice

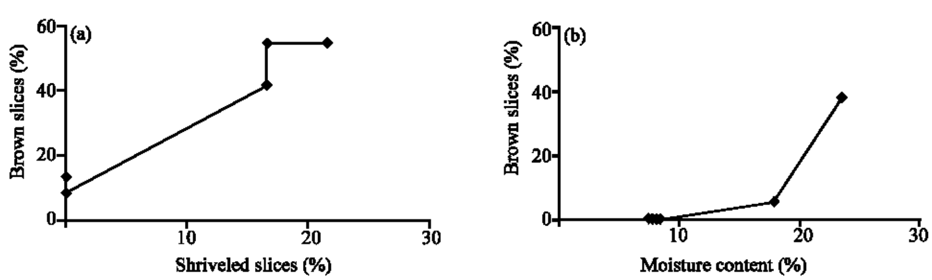

Fig. 6: Relationship between percentage of (a) shriveled slices and brown slices and (b) moisture content and percentage of mouldy slices

thicknesses from 1 to 4 mm, there were no mouldy slices and hence the percentage of acceptable slices increased from 13 to 58%. Then, as the slice thickness increased from 4 to 6 mm, the percentage of mouldy slices increased fro 0 to 38% whereas the percentage of acceptable slices decreased from 58 to 37% (Fig. 7b). Therefore, the percentage of acceptable slices was higher (more than 50%) at slice thicknesses 3 and 4 mm and percentage of mouldy slices of less than 5%.

The percentages of brown slices were higher (more than 50%) at slice thicknesses of 1 and 2 mm whereas the percentages of acceptable slices were 13 and 31%, respectively. At slice thicknesses of 4, 5 and 6 mm, the percentages of brown slices were lower (less than 14%). However, the percentages of acceptable slice were higher at 3 and 4 mm slices (53 and 58%, respectively) though higher percentages of brown slices were observed at 3 mm slice thickness (Fig. 7c). No shriveled slices were observed at slice thicknesses of 4, 5 and 6 mm whereas the percentages of acceptable slices were 58, 47 and 37%, respectively. At slice thicknesses of 1 to 3 mm, relatively higher percentages of shriveled slices were observed (more than 16%) and hence the lower the percentages of acceptable slices mainly at 1 and 2 mm. At 3 mm thickness, the percentage of acceptable slice was comparable with 4 mm thickness (Fig. 7d). Moisture content was higher for thicker slices whereas the percentages of acceptable slices increased with an increase in slice thickness and reach its optimal at slice thickness of 4 mm and abruptly decreased (Fig. 7e). This showed that the percentages of acceptable slices were higher (more than 50%) at slice thicknesses of 3 and 4 mm with the moisture content in the optimal range (10 to 20%).

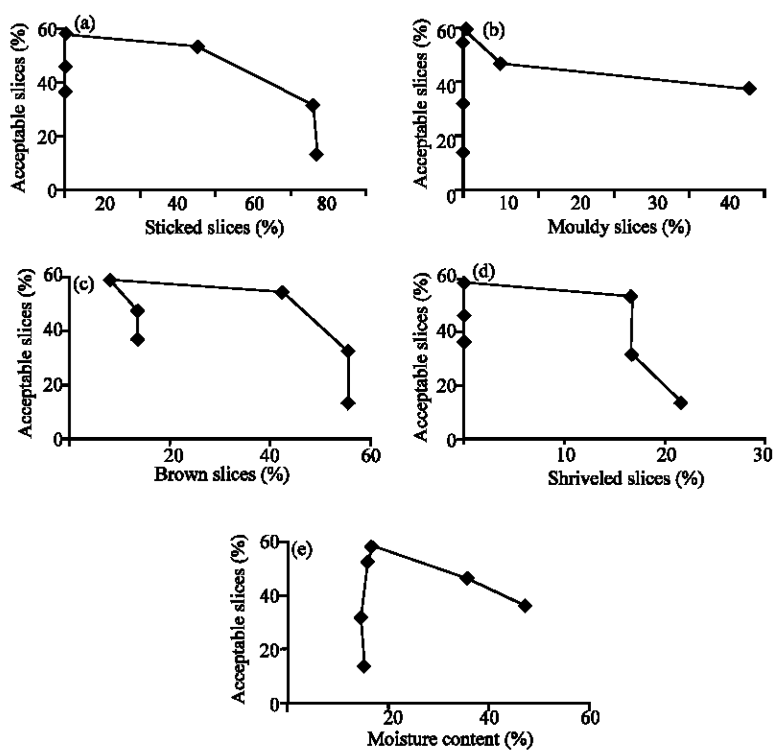

Fig. 7: Relationship between (a) percentages of sticked; (b) mouldy; (c) brown; (d) shriveled and (e) moisture content of slices and percentage of acceptable slices for slice thicknesses ranging from 1 to 6 mm

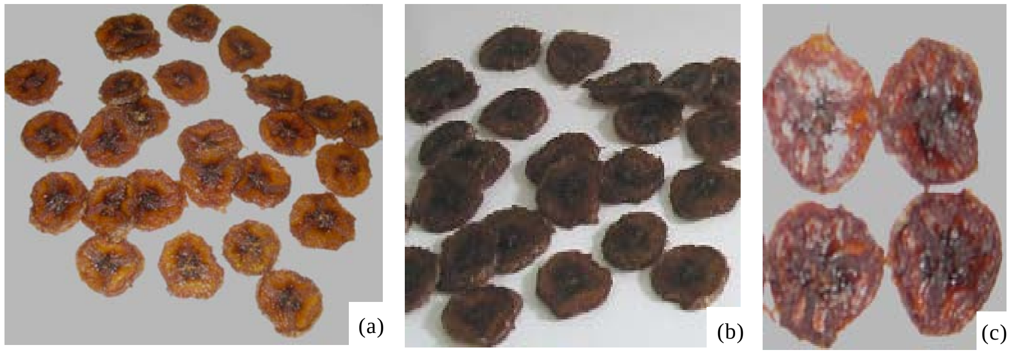

Fig. 8: Banana slices after four days of drying in NRI-modified local Kawanda cabinet solar dryer under Jimma condition: (a) acceptable, (b) unacceptable and (c) after two years of storage in polythene bags at room temperature (20 to 22°C)

It is important to cut and slice the peeled banana fruit to a particular thickness before solar drying to obtain good quality dried product. In our present study we clearly demonstrated that banana slice thicknesses ranging from 3 to 4 mm were optimum for solar drying considering all the response variables evaluated. We also confirmed that thicker pieces dried at slower rates than thinner pieces, very thin pieces tend to stick to the drying trays and difficult to remove and thicker pieces did not dry fully and subsequently deteriorate after packing. This is in line with previous reports (Brett *et al.*, 1996b). We have compared our dried products with the reference cards and the acceptable (Fig. 8a) and unacceptable (Fig. 8b) dried slices were presented for comparison. Dried banana slice after two years of storage in polythene bag was found to be promising regarding the colour (Fig. 8c). However, further investigation is needed about the physico-chemical characteristics of the dried product immediately after drying and at intervals of three to six months for one to two year.

Evaluation of the NRI-modified solar cabinet dryer: Solar dryers come in various forms and sophistication (Brett *et al.*, 1996a). A dryer should be adapted to local climatic conditions, local materials, local competence in building dryers, the products to be dried, the needs (quantity, taste and aspect of the product), the end users demands, operating costs and overall financial feasibility and flexibility to perform more than one function. Many designs of solar cabinet dryers have been evaluated and widely used in many parts of the world (Brett *et al.*, 1996a). Though the NRI-modified local Kawanda cabinet solar dryer was confirmed to be very suitable for solar drying of banana under Ethiopian condition, the size of the solar dryer is unmanageable to carry. Evidently, eight persons were required to carry the dryer. Its cost is also unaffordable by the resource-poor households. The total cost for purchasing the materials and for dryer construction was about 350 USD. As a result we have modified the size to one-third of the NRI-modified local Kawanda cabinet solar dryer (Fig. 9). The current dryer could be carried by only two persons as compared to the previous one which requires eight persons to be carried from place to place. Furthermore this can be affordable in terms of cost. However, the capacity is also reduced three times.

Transferable technologies and perspectives: In our present study we clearly demonstrated that banana slice ranging from 3 to 4 mm thicknesses were optimum for solar drying. Families and farmer's cooperatives that are intended to use the solar dryer for drying of banana could use the

Fig. 9: Solar cabinet dryer modified at Jimma University College of Agriculture and Veterinary Medicine (JUCAVM)

selected slice thickness of banana. The NRI-modified local Kawanda cabinet solar dryer can be used by groups of farmers and cooperatives. Households can easily use the JUCAVM-modified solar cabinet dryer since it is handy and cheaper to construct. Adoption of this technology can stabilize the seasonality of banana fruit in the market and increase the income of smallholder farmers by reducing postharvest loss. Finally, we suggest future work that focus on: (1) evaluation of the physico-chemical characteristics of the dried product immediately after drying and at intervals of three to six months, (2) evaluation of JUCAVM-modified cabinet solar dryer for drying of other fruits, vegetables and spices for small-scale households, (3) popularization of the solar dryer and establishment of small-scale fruit processing center at Potharvest Management Department of JUCAVM.

CONCLUSION

The present study was initiated to determine optimum thickness of banana slice for enclosed solar drying and to evaluate NRI-modified local Kawanda solar cabinet dryer under Ethiopian condition. From this study we recommend the use of NRI-modified rural Kawanda solar cabinet dryer for medium-scale drying whereas the JUCAVM-modified dryer for small-scale households using banana slice thickenesses of 3 and 4 mm. Furthermore, we suggest the need for further studies to investigate the physico-chemical characteristics of the dried banana product.

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