EFFECTS OF SUBSTITUTING SKIMMED MILK POWDER WITH MODIFIED STARCH IN YOGHURT PRODUCTION

E. M. Okoth[1], P. K. Kinyanjui[2], J. N. Kinyuru[3] and F. O. Juma[4]

[1, 2, 3] Department of Food Science and Technology, Jomo Kenyatta University of Agriculture and Technology, Kenya

[4]Corn Products International, Kenya

E-mail: muyanjica@yahoo.com

Abstract

Rheological properties of yoghurt are known to be influenced by several factors during processing including the milk composition, additives, the type of culture (ropy or non ropy), heat treatment and mechanical processes it undergoes after fermentation. The objective of this study was to determine the most appropriate levels of modified starch that could be added in the yoghurt without noticeably altering the keeping quality and consumer acceptability of the yoghurt. A stirred type of yoghurt was developed using modified corn starch as a stabiliser to variably replace skimmed milk powder (partially or in totally) while maintaining the same quality and consumer acceptability on the yoghurt product. Different formulations were made and their quality characteristics studied using the 3% skimmed milk powder sample as the control. The results showed that the modified corn starch addition did not affect the gelation process, texture, fermentation time and the desired pH end point. Two sample formulations were identified as the most comparable to the control in terms of viscosity, taste, mouth-feel and general acceptability. These were the 0.5% modified corn starch alone and 0.5% modified corn starch with 1% skimmed milk powder. These reduced the cost of production per litre by 22% and 13% respectively. The samples were stable for three consecutive weeks in all the desirable yoghurt quality parameters tested including consumer acceptability. In conclusion, the application of modified starch at the level of 0.4% was found to have the most significant reduction in cost of production while having the least effect on the keeping quality and consumer acceptability of the yoghurt.

Key words: Yoghurt, starch, quality, acceptability, cost

1.0 Introduction

Yoghurt is a milk product made by a fermentation process of fresh milk using lactic acid starter culture containing *Streptococcus thermophillus* and *Lactobacillus delbrukii ssp. bulgaris* to give a pH value of 3.8-4.6 (Tamine, 2002; Michelle *et al.*, 2005). Yoghurt can be regarded as a concentrated dispersion of particles in serum. Its total viscosity is given by the following formula $\eta = \eta_s \times f(Ø)$, where η is the total viscosity of the system, η_s is the serum viscosity of the aqueous phase and $f(Ø)$ is the function of the particle volume and their interactions in the matrix system (Marie *et al*., 2006). These factors contribute to desirable textural attributes of yoghurt. Rheological properties of yoghurt are known to be influenced by several factors during processing, the milk constituency itself (protein content, additives), the type of culture (ropy or non ropy), heat treatment and mechanical processes it undergoes after fermentation. The mechanical processes include stirring, pumping through pipes and filling which exposes it to shear resulting in a viscosity decrease. Rheological and stability properties of yoghurt can be modified by fortifying the milk with dairy – based ingredients, non-dairy ingredients or a combination of both prior to heat treatment and acidification (Oh *et al*., 2006). Non-dairy additives like polysaccharides such as starches can be used in yoghurt in conjunction with dairy ingredients or on their own to modify the rheological properties. Yoghurts made from different starches exhibit different rates of viscosity e.g. wheat starch showed highest shear consistency compared to other varieties (Keogh and O'Kennedy, 1998). Changes in the native structures of both milk proteins and starch occur upon heat treatment above their relevant critical temperatures during pasteurization. The heat treatment of milk at temperatures above 70°C results in denaturation of the whey proteins (Anema and McKenna, 1996). These denatured whey proteins can undergo a complex series of aggregation reactions with other denatured whey proteins and with the casein micelles (Anema and Li, 2003). In contrast, starch 'gelatinize' when heated in the presence of water, with the critical temperature dependent on the type of starch.

Starch gelatinisation encompasses disruption of the granular structure, swelling and hydration, and solubilization of starch molecules. Swelling is accompanied by leaching of granule constituents, mostly amylose, and the formation of a three dimensional network in the serum. The swelling that develops in such a mixed system of milk and starch during heat treatment may lead to different rheological characteristics in the final yoghurt gel and consequently in the stirred yoghurt product compared to that made from milk alone (Narpinder *et al*., 2003). The swelling property of starch is depended on its amylopectin content, amylose acts both as a diluent and inhibitor of swelling (Tester and Morrison, 1990). Starch exhibits unique viscosity behavior with change in temperature, concentration and shear rate (Nurul *et al*., 1999). Starch behavior in a system like that one of yoghurt, will also depend on their physical and chemical characteristics, such as mean granule size distribution, amylase/amylopectin ratio and mineral content.

Rheological characteristics of casein gels depend on the number and strength of the bonds between the casein particles, on its structure and the special distribution of the strands making up these particles (Roefs *et al*., 1990). Heating milk at a temperature above 80^{o}C produces gels with elastic modulus (G') of up to 450 Pa. In gels the resistance against deformation is proportional to the number of contact points per cross-section of the network. Cross-linking/bridging of denatured whey proteins in the gel has been postulated to be responsible for this high G' modulus of the network (Lucey *et al*., 1998). Large deformation/destructive tests of yoghurt with and without starch provide information on properties that may be related to the consistency of yoghurt gel during consumption. They also provide information on the resistance of the gel to processes such as stirring, pumping and other shearing operations which are used in production of stirred yoghurt (Ronnegard *et al*., 1993).

Addition of starch, a low cost polysaccharide to milk prior to heat treatment and acidification/fermentation modifies the properties of the acid gels (Decourcelle *et al*., 2004; Keogh and O'Kennedy, 1998; Wong *et al*., 2007). This includes thickening and gelling properties. Starch is the most widely used additive in the food industry for this purpose (Basim *et al*., 2004). It is used in yoghurt to increase its viscosity, improve its mouth-feel, and prevent syneresis. It also helps keep the fruit uniformity mixed in the yoghurt where applicable. Starch granules imbibe water and swell to many times their original size, resulting in increased viscosity of the solution (Gaston *et al*., 2007). It is one of the most frequently used thickening agents in yoghurt production due to its processing ease and low cost when compared to other hydrocolloids (Foss, 2000). Certain additives such as flavourings or fruit concentrates tend to reduce the consistency of the product which, therefore, generally needs some stabilization with products like starch (Ramaswamy and Basak, 1992). In practice, milk-based proteins such as skimmed milk powder, whey proteins and caseins are often used in yoghurt to improve its viscosity and stability. However starch gives a cheaper product than these milk based additives. Further, modified starch is not widely used in Kenya though it is expected to have a better output as compared to the non-modified starch commonly used in yoghurt production by some dairy industry players in Kenya. The aim of this research was therefore to develop a shelf stable, low cost and acceptable modified starch stabilised yoghurt, with a sufficient shelf life and thereby reduce the cost of stirred yoghurt production without compromising quality and customer acceptability.

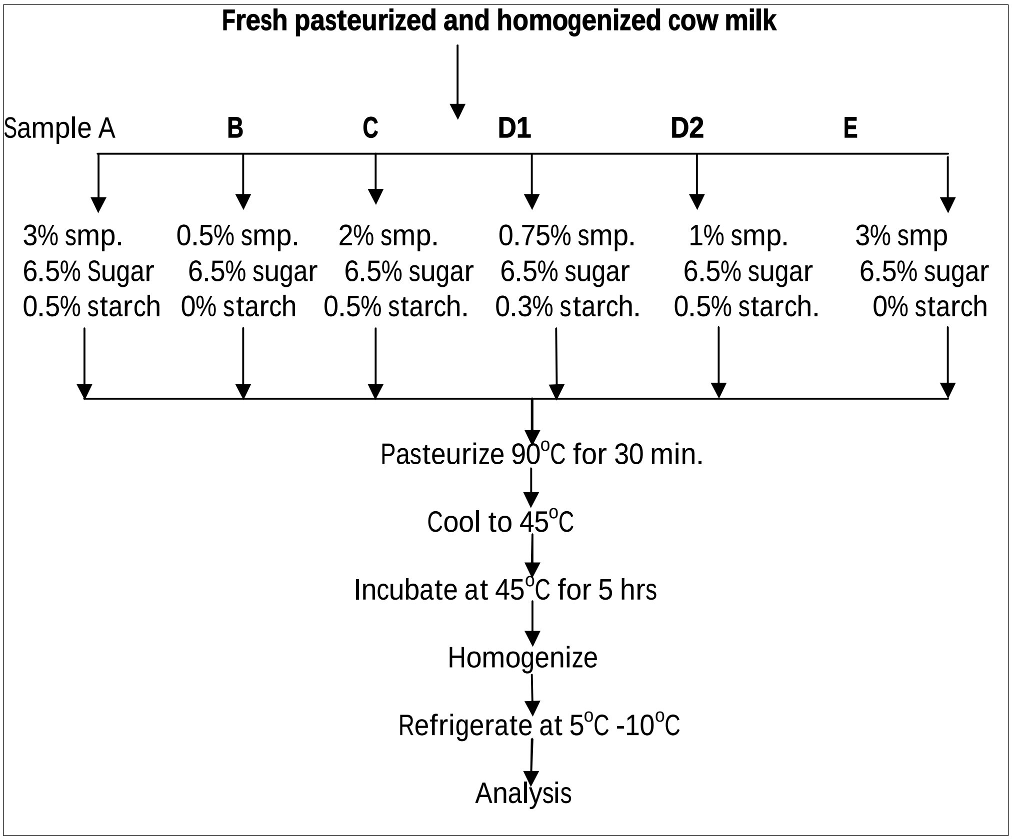
2.0 Materials and Methods

2.1 Yoghurt Production Raw Materials

The fresh milk of acceptable organoleptic and microbial quality was obtained from a local supplier. Sucrose used was obtained from a local wholesaler in a shop outside Jomo Kenyatta University of Agriculture and Technology. The starter culture used was obtained from Chr Hansen (YFL 811®) through an appointed agent (Pradip Enterprises) in Nairobi, Kenya. This is a thermophillic yoghurt starter culture with *Streptococcus thermophilus* and *Lactobacillus bulgaricus* micro-organisms. The skimmed milk was obtained from New Kenya Cooperative Creameries (NKCC) which contained 3.2% moisture. The modified corn starch used (Snow-Flake R 6704®™), was obtained from Corn Products International (Kenya Office) produced by Corn Products Brazil. The modified starch contained 14% moisture and had a pH of 4.5. The liquid milk used in the yoghurt making was first analysed to ascertain its composition. The same milk was used for all the formulations in a given batch. On average the fresh milk used contained 3.9% butter fat, 0.15% titratable acidity, 12.63% total solids, 8.73% solids non-fat, pH of 6.7 and a density of 1.029%.

2.2. Yoghurt Formulation and Production

Yoghurt was processed as shown in the flow chart below (Figure 1). The milk used in yoghurt production was analysed to ascertain its composition to allow batch to batch comparisons. Yoghurt-milk with 3% skimmed milk powder was used as the reference sample. The modified starch and skimmed milk powder were mixed with sugar prior to addition to the milk as shown in Figure 1. The same batch of skimmed milk powder, sugar and modified corn starch were used to allow comparisons from batch to batch. The milk was heated to 40ºC and the mix added. The samples were then pasteurized at 90°C for 30 minutes in a boiling pan. The milk was then cooled to 45ºC and inoculated with 0.02% thermophilic lactic acid starter culture. It was stirred for about 30 seconds for complete dissolution and equal distribution of the culture granules in the milk. The milk was incubated at 45°C for 5 hours until a firm curd was formed at the top and a pH of 4.1 - 4.4 was obtained. This was then aged at 10ºC overnight to allow for cooling. The curd was broken by swirling 40 times with a hand stirrer to form a smooth homogeneous product. It was then stored under refrigeration at a temperature of 8ºC for further analysis and storage stability tests.



Key: smp – skimmed milk powder

Figure 1: Standard flow chart for yoghurt processing

2.3 Analysis

2.3.1 Visual Observation

The stirred yoghurt was poured on a black plate which had been tilted at angle of 30˚ to allow it to flow (Lucey and Singh, 1998). Observations were made on consistency and body texture, to determine if the addition of starch had any observable effect on these parameters, for example, flaking.

2.3.2 Viscosity

2.3.2.1 Yoghurt Viscosity

The viscosity was measured using an imitation of a modified Ford cup (Posthumus funnel), (Galesloot, 1958) with a diameter of 12.5 cm at the top, diameter of 1.5 cm at the exit opening and a length of 13 cm as shown in Figure 2 below. The measurements were taken at 8°C. To monitor the change of viscosity with shear, 500 ml samples were poured through the funnel twenty times consecutively. The temperature was maintained at 8°C by keeping the samples under ice bath. The funnel was also dipped in ice water for 2 minutes after every five measurement to maintain this temperature. The viscosity is given by the time taken for a given amount of yoghurt to flow through the funnel in seconds. The longer it takes, the more viscous the yoghurt becomes.

Figure 2: 'Posthumus funnel apparatus'

The viscosity was also measured using Brookfield viscometer model BM type (Keogh and O'Kennedy, 1998). Three readings from each sample were taken and an average recorded. The readings were taken at 10ºC, the temperature at which yoghurt is consumed. The speed of the spindle used was adjusted according to the thickness of each sample. In this case, the specification combination used was speed 12 (revolutions per second) and spindle number 4. To get the final viscosity in centipoises, a factor of 500 was used to multiply the figure obtained.

2.3.3 Sensory Evaluation

The six samples coded A, B, C, D_1, D_2 and E were presented to a 15-member consumer panel drawn from the staff and students community of the Food Science Department of Jomo Kenyatta University. The yoghurt samples were tasted and rated using a 7 point hedonic scale; 1-dislike it very much to 7-like it very much. The parameters scored were viscosity, mouth-feel, taste, general perception and acceptability (Keogh and O'Kennedy, 1998)

2.3.4 Storage Stability Tests

The samples were kept under refrigeration (8°C). Viscosity, pH, visual appearance and organoleptic changes were monitored for a period of three weeks (Keogh and O'Kennedy, 1998).

2.3.5 Yoghurt Costing

The costing of all yoghurt samples was done. This was to determine the cost implication of substituting skimmed milk powder with starch. However, only the direct materials used were considered and the other indirect cost like labour, power and overheads were left out since they were assumed to be uniform for all the samples, hence not included in the costing. The cost of the milk used was Ksh. 40.00 per litre, the skimmed powder was Ksh. 500.00 per kilogram, the sugar was Ksh. 90.00 per kilogram and the modified starch was Ksh 250.00 per kilogram.

3.0 Results

3.1 General

3.1.1 Acidification

The pH obtained for all the samples at the end of the fermentation/incubation period of 5 hours ranged between 4.1 and 4.3 as shown in Table 1. The final pH attained by the different yoghurt formulations was almost similar. The fermentation times were also not affected by the addition of modified starch as they had all attained the requisite acidity level after being subjected to similar fermentation times.

3.1.2 Visual Appearance

The texture and grain of all the samples obtained were found to be smooth and fine respectively. This can be seen in the pictorial image (Figure 3). These were acceptable visual quality parameters. On the basis of texture and grain, one could not differentiate the yoghurt samples which contained starch from those which did not contain any starch. This showed that the modified starch was completely soluble in the milk, thus giving smooth, viscous yoghurt. The samples containing starch gave the same visual appearance of consistency as those that had milk powder.

3.2 Viscosity

3.2.1 Viscosity by Brookfield Viscometer

Samples A (3% skimmed milk powder plus 0.5% modified starch) and C (2% milk powder plus 0.5% modified starch) were most viscous/thick, registering a viscosity of 8080η and 7600η respectively as shown in Figure 4. These were significantly different from the control sample E (3% skimmed milk powder) which had a viscosity value of 4750η. Sample B had a viscosity of 5000η which was comparable to the Control sample E (4750η)

3.2.2 Viscosity by Posthumus Funnel Method

Sample A registered most time which is an indication that this was the most viscous (thick) sample followed by sample C as shown in Figure 5. It was found to support the results obtained by using the Brookfield viscometer. The mean time taken to run samples B (15.5 sec) and D_2 (15.1 sec) were comparable (not significantly different) from the control sample E (16.3 sec). Sample B had 0.5% corn starch and no skimmed milk powder, while sample D_2 had 0.5% corn starch and only 1% skimmed milk powder. Sample D_1 registered the least mean time in seconds. This is also an indication that the viscosity was the lowest of all. In this sample, 0.75 % skimmed milk powder and 0.3% starch were used.

3.2.3 Effect of Handling on Viscosity Using the Posthumous Cup Method

During handling and packing of yoghurt, there is a decrease in viscosity which can be simulated by passing the yoghurt through the posthumous cup twenty times to determine the effect of handling on the yoghurts viscosity where the results in Figure 6 were obtained. Sample A had the most viscous / thick product with a rum time of 45 mean seconds. This was in agreement with the results obtained on determining the viscosity by Brookfield viscometer. It was followed by sample E (control sample) with a run time of 33 seconds. Samples B, C, D_2, had a similar run times. However sample D_2 had a similar run time from the 7^{th} run to the 20^{th} run with that of sample E (control). This indicates that sample D_2 was most comparable in retained viscosity to the control (E). This also agrees with the results obtained in the determination of viscosity by the Brookfield viscometer and by the use of the Posthumus cup and also to the results of Lucey and Singh (1998). However, sample B was still cheaper than C since it had corn starch only as a stabilizer while sample C had both 0.5% starch and 1% skimmed milk Powder.

3.3 Sensory Evaluation

Sample E which was the yoghurt made with skimmed milk powder alone was ranked the highest on all the parameters as shown in Figure 7. It was not significantly different from sample D_2 on all the parameters tested ($p \leq 0.05$). It was not significantly different from C on viscosity/consistence ($p \leq 0.05$), not significantly different from sample A on mouth-feel and taste ($p \leq 0.05$). Sample D_1 scored the least on mouth-feel and taste. This is because it was least viscous. It had low starch (0.3%) and skimmed milk powder 0.7%.

3.4 Keeping Quality

After storing the samples for three weeks, all the products were found to be smooth and homogeneous on pouring. There was no wheying off or syneresis. There were no off flavours detected, thus fit for consumption**.** The results (Figure 8) exhibited different patterns on viscosity change on storage for the different samples. Samples A, B, C and E showed a decrease in their viscosity from week 1 to week 2 and then an increased past week 2 onwards. This shows stabilization and aging of starch on long storage which lead to increase of viscosity after two weeks of storage. For D_1, its viscosity increased from week 1 to week 2 then showed a decrease after the second week. This could be explained by the fact that the sample did not have the optimum solids and therefore during the time of stirring on determining the viscosity, the yoghurt network system collapsed easily. Viscosity change on sample D_2 recorded increase through all the three weeks. This is a sign of a stable yoghurt system as a result of sufficient solid present. Thus when starch is used for stabilization the product should be given a few days for its viscosity to age and stabilize. The pH recoded a stable pattern too in the three weeks of storage. Samples A, B, C, D_1 and D_2 had an average pH of 4.2 throughout the three weeks of storage period. Sample E had a higher pH initially (pH 4.3) and went up slightly to 4.4 for the next two weeks. The pH was stable over the storage period and was within the expected range as documented in other studies (Lucey and Singh, 1998).

3.5 Cost of Production

The results obtained on costing the yoghurt samples showed a distinct price difference between samples as shown in Figure 9. Sample A was the most expensive product costing Ksh. 57.20 per liter. This was not significantly different from the control sample E which was costing Ksh. 55.30 per liter. Both were significantly different from samples B, D_1 and D_2, which were costing Ksh. 42.80, 45.80 and 47.60 per liter respectively. Samples B and D_2 were samples most acceptable and comparable to the control sample E in most of the quality parameters tested. When their price was calculated, they were found to be lower by Ksh. 12.50 and Ksh. 7.7 per liter respectively as compared with sample E. This translated to a cost cut of 22% for producing yoghurt sample B and 13% for producing yoghurt sample D_2.

3.6 Model of the Effect of the Modified Starch on Viscosity

On analysis of the viscosity results obtained using the SPSS software package, the effects of the starch was found to be very significant at 5% level of significance with a significance of 0.042. It was also noted that the skimmed milk powder had a significant effect at the 5% level of significance with a significance level of 0.048. This implied that the starch had a greater effect on the viscosity than the skimmed milk powder. Further analysis was carried out to determine the various β to fit in the equation:

$\eta = \beta_1 x_1 + \beta_2 x_2 + \beta_3$

where;

η = total viscosity

$\beta_{1=}$ effect of skimmed milk powder coefficient

$x_{1=}$ percentage of milk powder added

$\beta_{2=}$ effect of starch coefficient

$x_{2=}$ percentage of starch added

$\beta_{3=}$ the y-intercept coefficient.

From the SPSS output,

$\beta_1 = 1227$

$\beta_2 = 6701$

$\beta_3 = 1092.5$

Therefore,

$\eta = 1227x_1 + 6701x_2 + 1092.5$

where: η = total viscosity;

x_1 = percent skimmed milk powder content;

x_2 = percent starch content

4.0 Discussion

During fermentation, the ingredients added have different effects, some of which include the increase or decrease of the fermentation times and the final pH attained. The pH range attained by the yoghurts in this study (Table 3) was in agreement with the results of yoghurt fermentation in other studies (Lucey and Singh, 1998; Oh *et al*., 2006), which established it to be between 3.8 and 4.6. This was the first indication that addition of corn starch as a stabilizer did not affect the fermentation process both in fermentation time and final pH attained. This is a very important criteria since an increase in processing times means an increase in cost of production (Oh *et al*., 2006).

From visual observation, one could not differentiate between the yoghurt samples which contained starch from those which did not contain any starch. This showed that the starch grains were completely solubilized in the milk, thus giving smooth, viscous yoghurts. This was as a result of the starch granules embedding in the continuous protein network during the milk heating process before the fermentation commenced (Oh *et al*., 2006). This then led to an increase in the

concentration of the protein net work due the increase in size of the gelatinized starch granules leading to the formation of large protein particles which gave a thick consistency (Lucey and Singh, 1998; Roefs *et al*., 1990). The thick consistency might also have been enhanced by the higher serum viscosity as a result of starch constituents leaching out during starch gelatinization, which increased the viscosity of the aqueous phase and consequently a thick smooth consistency/appearance as visually seen (Narpinder *et al*., 2003 ; Oh *et al*., 2006).
These yoghurts on being subjected to further analysis by the use of a Brookfield viscometer showed similar results. Based on the results obtained, it was observed that it is possible to make yoghurt of acceptable viscosity incorporating modified starch only at the rate of 0.5% without adding any skimmed milk powder. It was also established that it is possible to make yoghurt with as reduced skimmed milk powder content such as 1% instead of 3%, while substituting the milk powder with 0.5% modified starch.

In determination of the viscosity by the use of a Posthumus cup, sample D_1 registered the least mean time in seconds. This is an indication that the viscosity was the lowest of all. This showed that the stabilizer amounts (0.3% modified starch) used were not effective or were too low to give the desired viscosity (Lucey and Singh, 1998). In this sample, 0.75 % skimmed milk powder and 0.3% starch were used. This indicated that the amount of corn starch required to produce a comparable product in viscosity to that of reference/control (E) aught to be not less than 0.5%. These results are in agreement with those obtained by the use of a Brookfield viscometer.

As earlier mentioned, yoghurt handling has a viscosity reducing effect on the yoghurt. However this reduction is dependent of the yoghurt ingredients. In general, a trend of decrease of posthumus mean seconds was observed in all the samples as the number of runs increased. This was brought about by the strong deformation of the gel particles in elongational flow during the repeated flow tests. It led to large deformation, break-up and pressing out of the gel particles, leading to a decrease in apparent viscosity thus recording less time in each subsequent run.

The results are in agreement with those obtained by Galesloot *et al*. (1958), who found that the flow time decreased with an increasing number of times that the sample of yoghurt passed through the funnel. The Posthumus results from the different tests showed that the samples exhibited shear thinning behaviour, as indicated by the reduced time on subsequent run which is in agreement with the findings of Alistair (1995). However Sample D_2 with 1% skimmed milk powder and 0.5% corn starch stabilizer was most comparable to the reference sample (E). This further confirmed that it was possible to produce a high quality stirred yoghurt product with starch as the only thickener and completely eliminating the use of skimmed milk powder. This confirmed the findings obtained by Ramaswamy and Basak (1992). On subjecting the different yoghurts to production costs analysis, the difference realized in monetary terms was 22% per liter for sample B and that of 13% per liter for sample D_2 which would translate to huge profits in a long term mass production. All this has been achieved without compromising the quality and consumer acceptability of the yoghurt which confirms the results obtained from other studies albeit with non-modified starches (Decourcelle *et al*., 2004; Keogh *et al*., 1998; Oh *et al*., 2007).

5.0 Conclusion and Recommendations

By substituting skimmed milk powder with modified corn starch, it was possible to cut the cost of producing stirred yoghurt product by as much as 22% without compromising its quality and consumer acceptability.

It is recommended that the results obtained should be implemented to produce this high quality and profitable yoghurt. This ought to be done in phases with the first phase involving its production hand in hand with the control (3% skimmed milk powder) then gradually be made alone as the acceptability of the wider market is assessed.

Acknowledgements

We wish to thank the Department of Food Science and Technology, JKUAT and Corn Products International, Kenya for availing the resources required for the successful completion of this study.

References

Alistair M. S. (1995). Food Polysaccharides and their applications. TX553. P65F66 95-15184. pp 1-123.

Anema, S. G. and Li, Y. M (2003). Association of denatured whey proteins in with the casein micelles in heated reconstituted skimmed milk and its effect on casein micelle size. Journal of Dairy Research, **70**, pp 73-83.

Anema, S. G. and McKenna, A. B. (1996). Reaction kinetics of thermal denaturation of whey proteins in heated reconstituted whole milk. Journal of Agriculture and Food chemistry**, 44**, pp 422-428.

Ares G., Goncalvez D., Perez C., Reolon G., Segura N., Lema P., Gambaro, A. (2007). Influence of gelatine and starch on the instrumental and sensory texture of stirred yoghurt. International journal of Dairy Technology, **4**, pp 263-269.

Basim A., Hazim M., and Ammar E. (2004). Rheology of starch–milk–sugar systems: effect of starch concentration, sugar type and milk fat content. Journal of food engineering, **64**, pp 207-212.

Foss J. W. (2000). How processing affects Starch Selection for yoghurt. Bridgewater, NJ: National starch and Chemical Company.

Galesloot T. E. (1958). Investigations concerning the consistency of yoghurt. Netherlands Milk and Dairy Journal, **12**, pp 130-161 (summary pp. 161-165)

Koegh M. K. and O'Kenedy B. T (1998). Rheology of stirred yoghurt as affected by added milk fat, protein and hydrocolloids. Journal of Food Science, **63**, pp 108-112

Lucey J. A. and Singh H. (1998). Formation and physical properties of acid milk gels: a review. Food Research International, **13**, pp 529-542.

Narpinder S., Jaspreet S., Lovedeep K., Navdeep S. S. and Balmeet S. G., (2003). Morphological, thermal and rheological properties of starches from different botanical sources. Food chemistry, **81**, pp 218-231.

Narpnder S., Lovedeep K., Kawaljit S. S, Jagdeep K., and Katsuyoshi N. (2006). Relationship between physicochemical, morphological, thermal, rheological properties of rice starches. Food hydrocolloids, **20**, pp 532-542.

Nuruli M., and Azemi B. M. (1990). Rheological behaviour of sago (Metroxylon sagu) starch pastes. Food chemistry, **64**, pp 501-505.

Oh H.E., Anema S. G, Wong M., Pinder D. N., and Hemar Y. (2006). Effect of potato starch addition on the acid gelation of milk. International Dairy Journal, **17**, pp 808-815.

Rasmaswamy H. S., and Basak S. (1992). Pectin and raspberry concentrate effects on the rheology of stirred yoghurt. Journal of Dairy Science, **81**, pp 1525-153.

Roefs S. P. F. M., de Groot-Mostert A. E. A. and van Vliet T. (1990). Structure of acid casein gels. 1. Formation and model of gel network. Colloidal and surfaces **50**, pp 141-159.

Ronnegard E. and Dejmek P. (1993). Development and breakdown of structure in yoghurt studied by oscillatory rheological measurements. Lalt73, pp 371-379.

Tamine A. Y. (2002). Fermented milks a historical food with modern application. A review. European Journal of clinical nutrition, **56**, S2-S15.

Teggatz J. A. and Morris H. A. (1990). Changes in the rheology and microstructure of the ropy yoghurt during shearing. Food Structure, **9**, pp 133-138.

Tester R. F. and Morrison W. R. (1990). Swelling and gelatinization of cereal starches. Cereal chemistry, **67**, pp 558-563.

Waistra P., Wouters J. T., and Geurts T. J. (2006). Dairy science and Technology, Second edition, CRC Press. pp 15, 169-172, 290-291,450-451, 567-568.

Appendix

Table 1: pH of the milk at the beginning of fermentation and that of the end

Samples	**A**	**B**	**C**	**D_1**	**D_2**	**E**
PH (start)	6.5	6.5	6.5	6.5	6.5	6.5
pH (end)	4.2	4.3	4.2	4.1	4.3	4.3

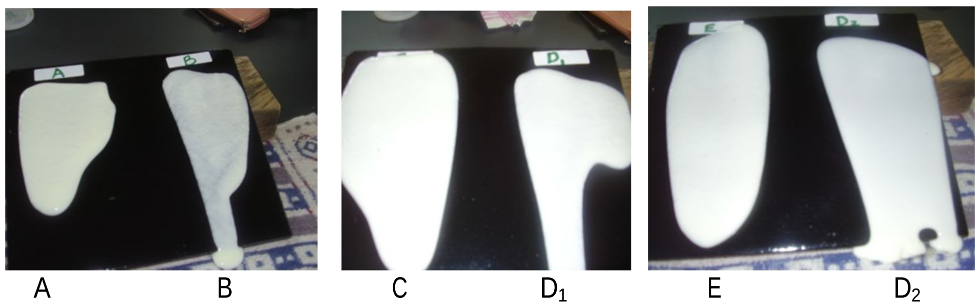


Figure 3: Photographs of the six stirred yoghurt gels on black plate

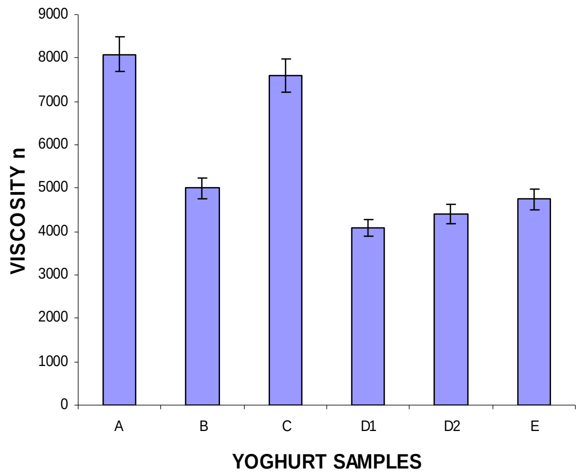


Figure 4: Effect of corn starch addition on yoghurt viscosity

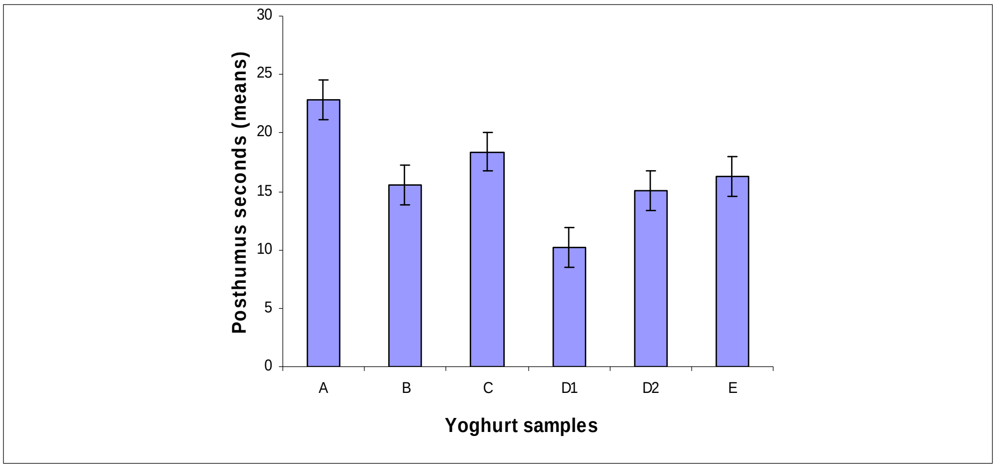


Figure 5: Posthumus mean seconds as an indication of yoghurt viscosity

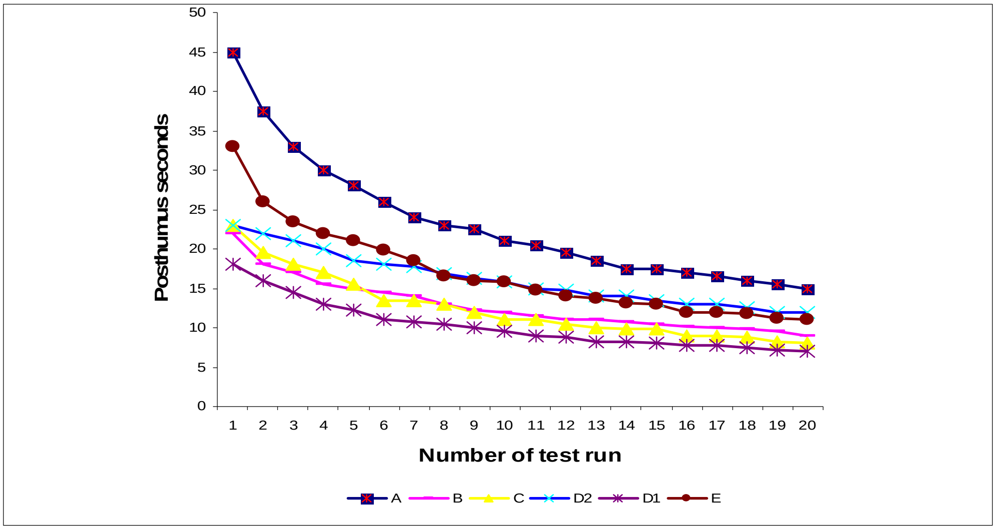


Figure 6: Posthumus Seconds 20X run curves

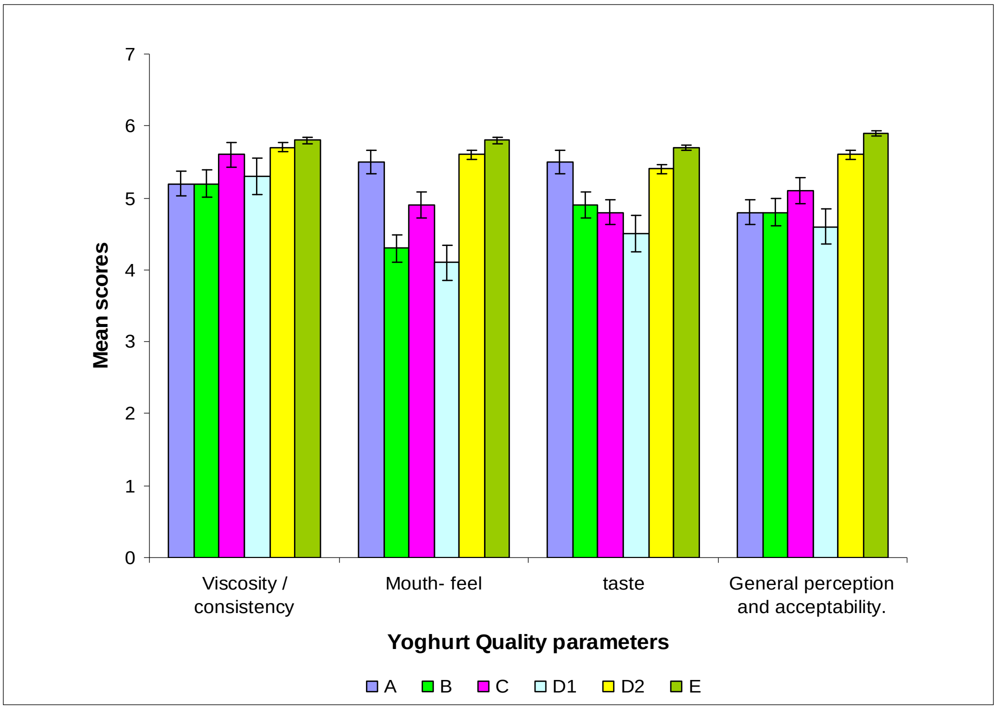


Figure 7: Sensory evaluation results of the six samples.

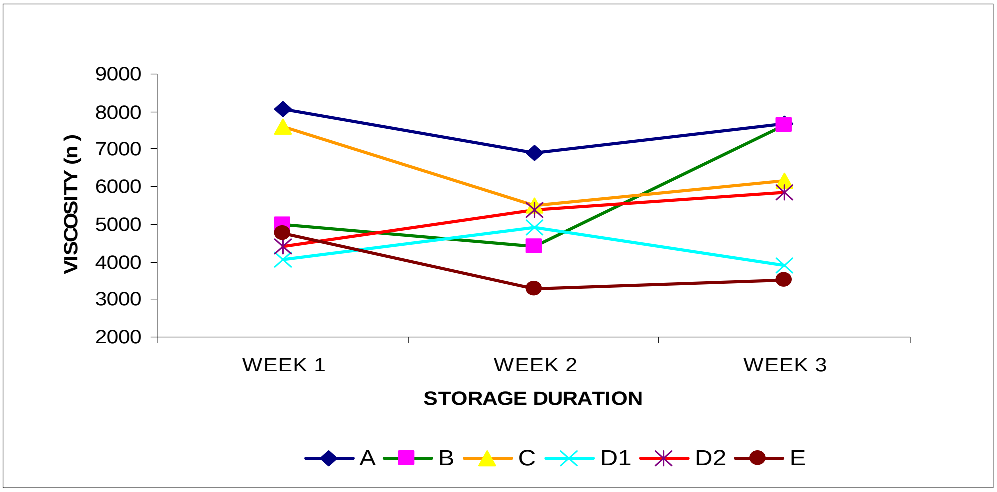


Figure 8: Viscosity change within 21 days of storage

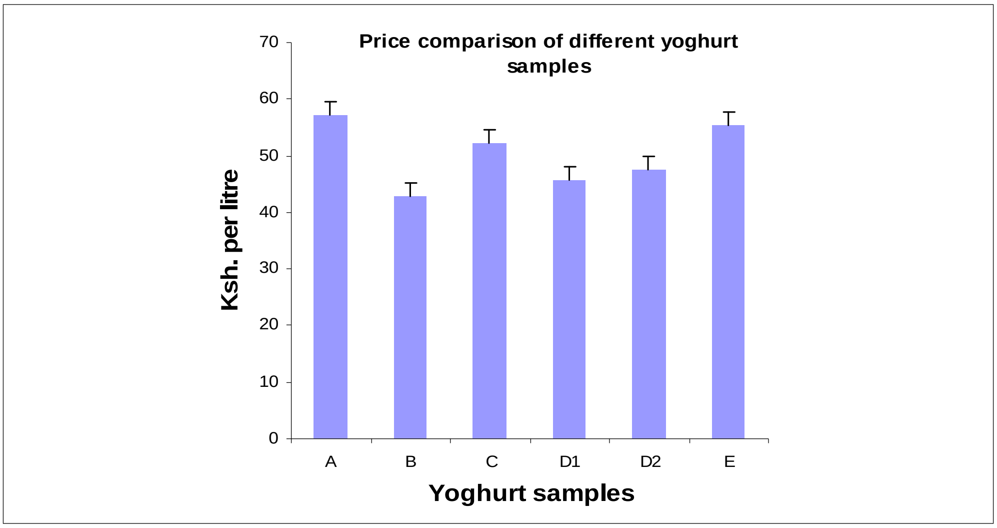


Figure 9: Cost comparison of producing different yoghurt samples