

Full Length Research Paper

# Characterization of two isolated lactococcal strains with respect to bacteriocin-concentrations

Babalola Olubukola O.

Department of Microbiology, Olabisi Onabanjo University, Ago-Iwoye, Ogun State, Nigeria. P.O. Box9536, UI HeadQuarters, Ibadan. E-mail: [olubukola\\_babalola@yahoo.com](mailto:olubukola_babalola@yahoo.com).

Accepted 23 February, 2019

*Lactococcus lactis* strains present in wara (local cheese), and nunu (skimmed sour milk) were isolated. These were *L. lactis* WO81 and N13L. Nisin assays were by agar diffusion test and turbidimetric assay. There was no successful detection of an inhibition zone with wara. However, *L. lactis* strain WO81 from wara was able to produce nisin. Exponential growth occurred for about 14 h after some lag phase. The optimum incubation time of 2 to 6 h was established. Nisin concentration decreased with a subsequent increase in the incubation period. The effect of inoculum size was found not to be conclusive but directional to an optimal size of 1.0% (V/V). The suitable working temperature of 30°C and the pH value of 6 were discovered. Investigations into the phosphate sources revealed  $\text{KH}_2\text{PO}_4$  as the best phosphate source. A physiological link is proposed between these functions, growth and nisin concentration. In the presence of sufficient glucose, growth was increased with the periodic addition of NaOH. Maximum nisin concentration was obtained when, at pH 6, the medium was buffered. In this study essentially it is noted that nisin has a lytic bactericidal mode of action.

**Key words:** Local cheese, 'wara', 'nunu', nisin, bacteria, bacteriocin.

## INTRODUCTION

Over two decades ago, Nettles and Barefoot (1993) reported several types of bacteriocins from food-associated lactic acid bacteria (LAB). Common among these are nisin, diplococcin and lactococcin (Ray et al., 2001; Fernandez et al., 2004; Corsetti et al., 2004), produced by *Lactococcus lactis*, a bacterium that occurs naturally in milk. Nisin has been the most extensively studied (Flores and Alegre, 2001). Nisin was the first bacteriocin derived from the fermentation of a lactic-acid bacterium and was approved by the FDA in April 1989 to prevent the growth of botulism spores in pasteurised processed-cheese spreads. Besides *Clostridium botulinum*, nisin inhibits a broad spectrum of bacteria, which include *Listeria monocytogenes*, *Staphylococcus aureus*, and *Bacillus cereus* (Bouttefroy et al. 2000; Jydegaard et al., 2000; Bizani and Brandelli, 2002; Risoen et al., 2004; Mataragas et al., 2002). Nisin is permitted up to various maximum prescribed levels in many countries of the world (Jack et al., 1995). The nisin is added exogenously, and allows manufacturers to make a higher moisture product without risk of spoilage or health concerns for the consumers.

This could be incorporated into Nigerian nunu (skim-

med sour milk) and wara (local cheese). Nisin offers processors a "clean" label as well as extending refrigerated shelf life by 14 to 30 days depending on the product (Morris, 1991). Ademuyiwa (1995) was able to isolate potential nisin-producing lactic acid bacteria from raw milk, nunu, and wara. A more advanced study on nisin-producing lactic acid bacteria seemed to be suitable and needed as a starting point for the delivery of safe nunu and wara to consumers, in line with today's microbiological safety rules for cottage industries.

Bacteriocins produced by isolates of *Lactobacillus* spp. from African fermented foods based on fermented maize (*Zea mays*), e.g. ogi and cassava (*Manihot esculenta* Crantz), e.g. fufu have been successfully characterized (Olukoya et al., 1993; Ogunbanwo et al., 2003) with respect to their inhibitory spectrum. However, in these studies and many more the microbial flora from nunu and wara were not characterised. Therefore, the objective of this study was to characterize nisin concentration among the isolates from nunu and wara. It was developed to include a study of the effects of inoculum size, incubation temperature, incubation time, pH, phosphorus source,

and the availability of NaOH, on the bactericidal activity of nisin.

## MATERIALS AND METHODS

Preparation of wara: Various workers have described the preparation of wara (Awoh and Egunleti, 1985; Raheem, 2006). The art of making wara was adopted from the Fulani housewives in the Northern states of Nigeria. The locally made soft unripened cheese is made from unpasteurized milk and coagulated with the juice extracted from the leaves of *Calotropis procera* (Raheem 2006). Some of the starters involved in fermentation of cheese are *Streptococcus cremoris*, *Staphylococcus aureus*, *Lactobacillus casei* and *Micrococcus* species. The starter cultures are undefined multiple strains. Ogundiwin (1978) simulated the traditional procedures in the laboratory and reported that it took 65 minutes to complete cheese manufacture. He observed that coagulation was effected at temperatures between 65 and 68°C at a pH range of 6.42 - 6.43. The processing time was between 30 - 35 min. The titratable acidity of most commercial cheese ranges from 0.2 - 0.27% and pH may be as low as 4.70. The increase in acidity is suggested due to post processing contamination by the lactic acid bacteria (Ogundiwin and Oke, 1983; Sanni et al., 1999).

Preparation of nunu: The Hausa women of Nigeria milk the cows, filling their long gourd containers. The raw cow milk according to Waters- Bayer (1985) was diluted by adding a mixture of water and kuka, a thickening agent made from the acid pith of baobab (*Adansonia digitata*) fruits constitute 'nunu' (skimmed sour milk). The pith of the kuka fruit is rich in vitamins B1 and C, can be mixed with water to serve as a refreshing drink, and is also used to treat intestinal disorders (von Maydell, 1983). The water used in dilution of the raw milk came from shallow wells or streams and was not boiled before use. The rate of dilution varied greatly between women. 'Nunu' is nutritious, refreshing and delicious when taken with 'fura' (millet powder), hence the popular 'fura de nunu' in the north-ern part of Nigeria. Variation in the local names ranges from fura de nunu, fura da nono, fura do nono. This Hausa delicacy abounds only during Ramadan (Moslem fasting month). Microorganisms that have been implicated in nunu include *Lactobacillus acidophilus*, *S. cremoris*, *Micrococcus luteus* and *L. lactis* (Akinyan-ju, 1989; Ademuyiwa, 1995). The starter cultures are undefined multiple strains since the fermentation generally depends on chance inoculation.

Test organisms and cultivation media: *L. lactis* strains (WO81 and N13L) were used as nisin-producing microorganisms. *L. lactis* N13L was isolated from nunu and strain WO81 was isolated from wara in our laboratory and identified by their morphological and biochemical properties (Ademuyiwa, 1995). Before use, the nisin-producing *L. lactis* strains (WO81 and N13L) were activated in de Man-Rogosa-Sharpe (MRS) medium, commercial medium developed to support good growth of lactic acid bacteria, (de Man et al., 1960). Nisin mode of action was tested quantitatively with *Bacillus subtilis* MOO1995, which was obtained from the collection at the University of Ibadan, Ibadan, Nigeria, was used as a test organism in the bioassay. *B. subtilis* MOO1995 was activated in Tryptone soya broth by incubating these overnight at 30°C. For the preparation of *L. lactis* cell-free supernatant (CFS), *L. lactis* strains were grown overnight at 30°C in MRS broth. After growth, cells were removed by centrifugation (10,000 g, 10 min) and the supernatant was filter sterilized. It was used immediately or stored at -20°C until used. Assays of nisin in cultures of lactococci: Bacteriocin selective medium (BSM) with the following composition: 2 g/l beef extract, 10 g/l tryptone, 4 g/l yeast extract, 2 g/l glucose, 8.7 g/l K<sub>2</sub>HPO<sub>4</sub>·3H<sub>2</sub>O, 8 g/l K<sub>2</sub>HPO<sub>4</sub>, 0.2 g/l MgSO<sub>4</sub>·7H<sub>2</sub>O, 0.05 g/l MnSO<sub>4</sub>, 1 ml tween 80, 15 g agar, 1 g catalase, was prepared and cooled to about 50°C. The suspension of the test organisms were diluted 1 in 10 with normal saline solution and 2 ml of this dilution were added to each 100 ml of BSM at 48°C with thorough mixing. The incubated medium was

poured to a depth of 3 to 4 mm into flat-bottomed sterile Petri dishes and allowed to solidify. The plates were then inverted and stored at 4°C for 1 h to facilitate the boring of wells. With the aid of a sterile cork borer (diameter = 1 cm) 3 wells were cut into the solidified medium and the disks so produced were removed and discarded. With a standard Pasteur pipette, the CFS was delivered in uniform quantities into the wells. The plates were covered and transferred carefully, without displacing the liquid in the wells, to a refrigerator (for the nisin to diffuse) for 12 h. Thereafter, the plates were transferred carefully to a 30°C incubator and left overnight. The diameters of the zones of inhibition were measured to the nearest 0.1 mm by means of a bisector.

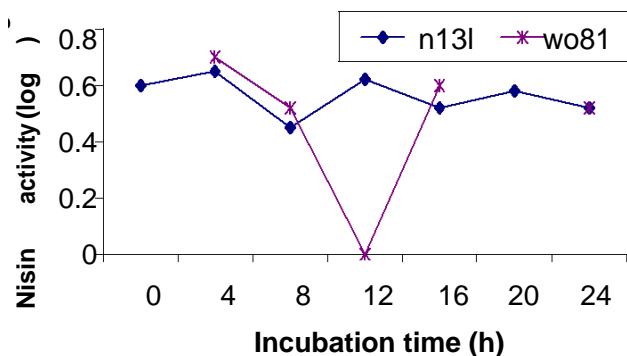
Determination of the modes of action of nisin: Nisin produced by *L. lactis* WO81 and N13L were tested by monitoring the growth of *B. subtilis* MOO1995 in CFS of *L. lactis*. The techniques of Tagg and McGiven (1971) and Benkerroum et al. (1993) were employed. Purified nisin and antibiotics such as streptomycin, ampicillin, azithromycin, nalidix acid, chlortetracycline (all from Difco), cefuroxin and ceftriaxone (both from Oxoid) were subjected to the same test as positive control. The purified nisin was a commercial preparation (Nisapilin).

Optimisation and physiological studies: *L. lactis* present in wara (WO81), and nunu (N13L) were each grown for 5 h at 30°C in 9 ml Bacteriocin Selective Medium (BSM) and subcultured for 10 h at 30°C in 70ml BSM. A fresh culture of actively growing cells was always used as the inoculum. Fermentation was run in Erlenmeyer flasks (500 ml) containing 300 ml production medium. The fermenter was operated at 30°C without aeration and slow agitation (50 rpm) was continuously provided to keep the fermentation broth homogenous. Samples of fermentation broth were withdrawn at 2 h intervals, and analysed for growth and nisin concentration to deduce the optimum incubation time. The centrifuged cells (10000, 10 min) were washed twice in saline (0.85% NaCl) (De Vuyst and Vandamme, 1992). The CFS served as nisin and assay was carried out by a turbidimetric method using *B. subtilis* MOO1995 (which is sensitive to nisin). Nisin concentration was measured as optical density (OD) at 660 nm using Beckman Du 7400 spectrophotometer. Bar charts of growth and nisin concentration against time for different sizes of inoculum were plotted. The inoculum sizes tested were 1% (v/v), 2% (v/v), 5% (v/v), 10% (v/v), and 15% (v/v), other-wise the inoculum size was maintained at 1% (v/v).

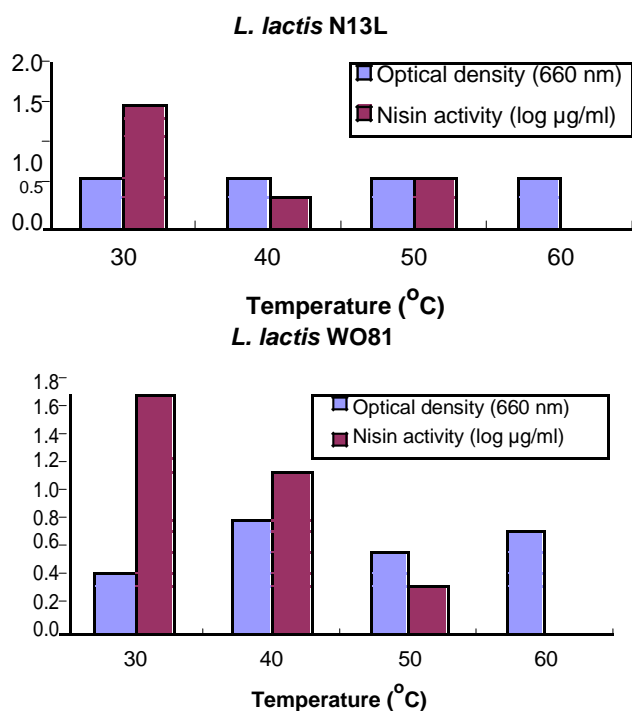
To establish the effect of different temperature regimens on growth and nisin concentration of the *L. lactis* strains, incubation was at different temperature regimens of 60, 50, 40, and 30°C. The initial pH of BSM broth was adjusted to 6.0. The levels of pH tested were 4, 6, and 8 for OD and 2, 4, 6, 8, and 10 for nisin activity; otherwise the initial pH of BSM broth was adjusted to 6.0. BSM broth was adjusted using 0.1 N HCl or 0.1 N NaOH where appropriate. The effect of different phosphorus sources was tested on growth and nisin concentration of the test organism using BSM supplemented with 4% glucose (instead of the 2% glucose used in basal BSM) and 1% of an inorganic phosphorus source (replacing phosphorus present in the basal BSM). The varying phosphorus sources tested were KH<sub>2</sub>PO<sub>4</sub>, K<sub>2</sub>HPO<sub>4</sub>, (NH<sub>4</sub>)<sub>2</sub>HPO<sub>4</sub>, NaHPO<sub>4</sub>·2H<sub>2</sub>O, Na<sub>2</sub>HPO<sub>4</sub>, Na<sub>2</sub>HPO<sub>4</sub>·H<sub>2</sub>O, and Na<sub>2</sub>HPO<sub>4</sub>·12H<sub>2</sub>O (all from BDH). The media were dispensed into cotton wool plugged into test tubes and sterilized by autoclaving at 121°C for 15 min. On cooling, the tubes that were prepared in triplicate were inoculated aseptically with a fresh culture of actively growing cells. Neutralization of the lactic acid formed by the growing cultures was by the periodic addition of 10N-NaOH. Samples were checked for growth by comparison with the same experiment without the periodic addition of NaOH.

## RESULTS

Two nisin-producing strains of *L. lactis* were isolated from local cheese (wara), and skimmed sour milk (nunu). Dur-



**Figure 1.** Effect of incubation time on nisin concentration (30°C) of two *L. lactis* strains over a 24 h fermentation period.



**Figure 2.** Effect of temperature regimen on growth and nisin production of *L. lactis* strains for 24 h in MRS broth at pH 6.0.

ing the demonstration of the bactericidal mode of action, the clearing around the well indicated the presence of nisin. A concentration of 0.48 µg nisin/ml was required to produce a measurable zone of inhibition (Figure 1). This is in accordance with Barry's (1986) report that the compound diffuses through the agar, setting up a concentration gradient. The concentration is inversely proportional to the distance from the well (Figure 1). A zone of no growth around the well indicates inhibition, which is the measure of nisin concentration.

For the agar diffusion method, no zones of inhibition were obtained when plates were incubated immediately

after being set up, but when growth of the *B. subtilis* MOO1995 was delayed by refrigeration for 24 to 48 h to allow time for the nisin to diffuse, some inhibition was apparent after subsequent incubation.

The data in Figure 1 were based on 6 separate experiments and showed the sequence of change taking place during cultivation for 24 h in BSM. An incubation period of 2 to 6 h was the most favourable for nisin production for both strains tested. *L. lactis* WO81 had a value of 0.74log µg nisin/ml at 2 h when the incubation period was for 2 h. This was to be the highest nisin concentration reached in the strain during the time-course study. At 12 h, nisin concentration in this strain was 0.0log µg nisin/ml. Subsequent incubation showed a decrease in nisin production. A gradual decrease was observed, probably due to a loss in bactericidal activity. Exponential growth occurred for about 14 h after some lag phase. Comparison between experiments showed that the length of the lag varied, the slope of growth curve varied, and the rate at which the nisin was formed during the experiment and subsequently disappeared also varied. The small amount of nisin introduced with the inoculum at zero time could not be recovered after incubation for 2 to 4 h when exponential growth started.

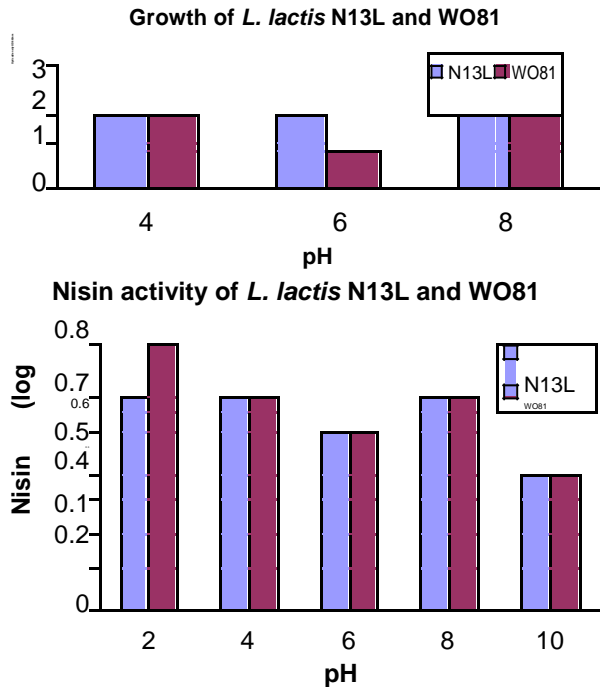
Time-course studies were made on the effect of inoculum size of *B. subtilis* MOO1995 on the nisin concentration by *L. lactis* strains N13L and W081 after 24 h at 30°C. The observations (data not presented) showed that with increasing inoculum size of the sensitive indicator organism, there was a simultaneous increase in nisin concentration up to 1 ml inoculum and a subsequent decrease in nisin concentration, but the correlation broke down after 14 to 16 h of growth. The pH value decreased as lactic acid accumulated. The initial pH 6.0 decreased to a pH within a minimum of 4.4 and a maximum of 5.09 in 24 h; during the same time the O.D. reading of the lactococci increased from 0.13 to 0.78. During the exponential phase of growth, the O.D. doubling time ranged from 0.11 to 16. The greatest amount of nisin was produced in the cultivation with the inoculum size of 1.0 ml.

The optimum temperatures for the production of nisin varied slightly with the two *L. lactis* strains examined (Figure 2). The optimum temperature recorded was 30°C. Nisin was detected at temperatures between 30 and 60°C (Figure 2).

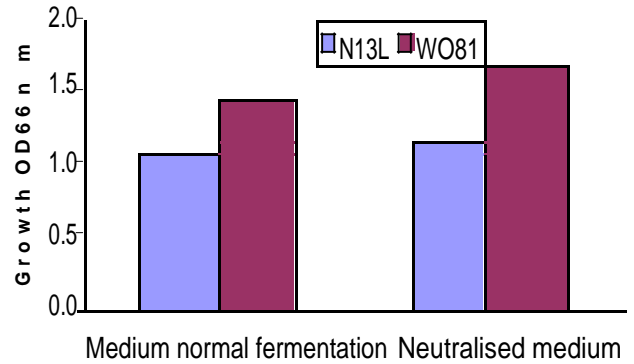
The cells of *L. lactis* WO81 reached O.D. of 0.18 after 8 h and had a bactericidal activity of 0.75log µg nisin/ml. Further incubation resulted in an increased O.D. but a rapid reduction in concentration.

Figure 3 shows the effect of pH on growth and nisin concentration. Both strains exhibited nisin production at all the pH levels. Growth and nisin concentration were optimal at pH 6 although at pH 4 greater nisin concentrations was demonstrated by both strains from 4 to 6 h. Less nisin concentration tends to be better retained at lower pH values.

The results are presented in Figure 4 of the influence of

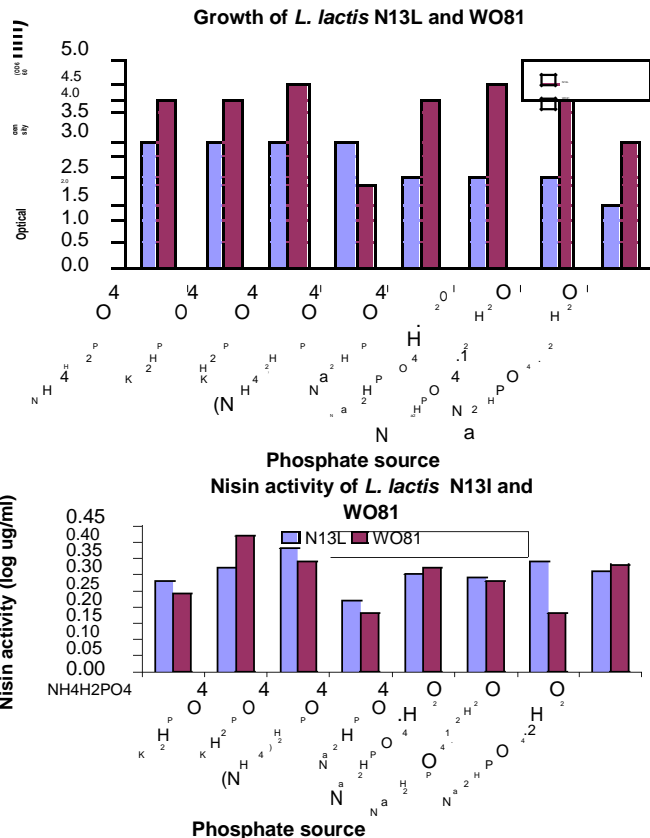


**Figure 3.** Effect of pH on growth and nisin production of *L. lactis* strains N13L and WO81 after 24 h at 30°C in MRS broth.



**Figure 5.** Effect of periodic addition of 10M – NaOH on growth and nisin concentration of *L. lactis* strains N13L and WO81 (Incubation time: 24 h).

different phosphorus sources tested. The two *L. lactis* strains showed an increase in growth by O.D. measurement with different phosphorus sources and the nisin concentration level was stimulated. In all,  $\text{KH}_2\text{PO}_4$  was found to be the best phosphorus source in that it gave the highest biomass and nisin concentration levels. Growing cultures of *L. lactis* are sensitive to sodium hydroxide. Periodic additions of 10M- NaOH were found to improve the O.D. reading with time (even with the BSM) by neutralizing of the acid formed (Figure 5).



**Figure 4.** Effect of phosphorus source on growth and nisin production of *L. lactis* strains after 24 h at 30°C.

## DISCUSSION

There was no successful detection of an inhibition zone with wara, as reported in the work of Mocquot and Lefebvre (1956) who worked on a cylinder of cheese. It was possible that local cheeses examined were not made with a starter that produces nisin. This was disproved by the spot and streak method of Benkerroum et al. (1993) which, when employed, showed that the local cheese also had strain of *L. lactis* able to produce nisin, for an example, *L. lactis* strain WO81 (Ademuyiwa, 1995). The absence of inhibition may be because the diameter of the zone of inhibition produced is dependent not only upon

the nisin concentration but also upon the amount of interfering substances present in the food extract. The difference in this research finding, compared to the report of Mocquot and Lefebvre (1956), may be because, unlike the wara that was used in this study, the cylinder of cheese had a smaller amount of interfering substances. According to Barry (1986), the size of the zone is dependent upon the rates of diffusion and cell growth.

The imperfect zone edge may be due to the unpurified quality of the nisin and also to the action of bacterial lysis, which cannot be exempted. When purified nisin and antibiotics such as streptomycin, ampicillin, azithromycin, naidix acid, chlortetracycline (all from Difco), cefuroxin and ceftriaxone (both from Oxoid) were subjected to the same test, perfectly sharp zone edges were obtained

(Ademuyiwa, 1995).

In this study essentially it is noted that nisin has a lytic bactericidal mode of action. This is in line with the works of Bhunia et al. (1991) and Ahn and Stiles (1990) who reported that the extent of inhibition produced by each strain varies. During the late logarithmic period, there was apparent destruction of nisin. This may be due to the role of nisin in the bactericidal growth cycle.

The broke down in correlation after 14 to 16 h of growth may be due to the commonest source of error of variable distribution of bacteria in each inoculum size, especially in samples showing low optical densities. However, as propounded by Rayman and Hurst (1984) these differences were considered to be inherent in experiments done with different inocula and in experimental batches of media. This experiment showed that a maximum limiting population density ( $M'$ -concentration, Bail, 1929) was reached with this culture.

There may be a physiological link between temperature, growth, and nisin concentration. This may be due to the direct effect of temperature on the microbial growth rate. This result gives credence to the works of Delves-Broughton (1990) and Van den Berghe et al. (2006), who reported optimum temperatures of 37 and 25°C for nisin production respectively. Similarly, Leroy and de Vuyst, (1999) reported that bacteriocin activity were very much influenced by changes in temperature and pH.

From this study it was found that pH is a controlling factor for nisin concentration. The results of Yang and Ray (1994) also identified that growing bacterial cells at optimum pH can increase the concentration of a bacteriocin in a simple medium. Nisin concentration was higher in the acidic range. The highest bactericidal activity obtained was at pH 2 to 4. This is in accordance therefore with the report of Bernard and Ferda (1991) that nisin is neither very active nor stable at high pH values. The optimum pH (6) for growth of the isolated strains affected their nisin concentration. There was a decrease in nisin concentration on either side of the optimum pH 6 and this agreed with the views of Liu and Hansen (1990), which state that nisin is most stable at pH 2 and its concentration decreases drastically at basic pH values between 8 and 9. Findings from this study clearly indicated that cell yield and nisin concentration levels are strongly stimulated by added phosphorus, irrespective of the type of phosphorus source. Additionally, Leroy and de Vuyst (1999) reported that the concentration of biomass was closely related to bacteriocin activity, indicating primary metabolite kinetics, but was not the only factor of importance. In agreement with the findings of De Vuyst and Vandamme (1993),  $KH_2PO_4$  was found to be the best phosphorus source for nisin concentration. It clearly demonstrates the potential of this mineral to specifically support the growth of lactic acid bacteria. Considering the positive correlation between biomass and nisin concentration levels (De Vuyst and Vandamme, 1991), the results in this study suggested that inorganic phosphate

stimulated nisin concentration.

Periodic additions of 10M-NaOH may improve optical density O.D reading due to the effect of neutralizing the acid formed when the nutrient did not become a limiting factor. Rogers and Whittier (1928) obtained similar results showing that when 10M-NaOH was periodically added to growing cultures of lactococci, considerable increase in growth was obtained. According to the fermentation profiles presented by Flores and Alegre (2001), the addition of 4M-NaOH has been demonstrated to reduce the lactic acid produced during fermentation and subsequently enhancing concentration of nisin. Matsusaki et al. (1996) also reported fermentation system with pH control via addition of NaOH.

Although nunu and wara are popular traditional milk products in Nigeria, their shelf lives are less than two days. In these milk products lactic acid bacteria were identified as the major part of the fermentation flora. In addition to the anti-microbially active organic acid bacteria produce bacteriocins, which can reduce the growth of spoilage organisms and improve the hygienic condition of the product (Lindgren and Dobrogosz, 1990; Olukoya et al., 1993; O'Sullivan et al., 2002), thus reducing the safety hazard the consumers are subjected to. As the spoilage bacteria compete with one another for the highly nutritious nunu and wara, bacteriocin-producing bacteria may make the prevailing condition unsuitable for food borne pathogens and spoilage organisms. Hence its potential uses as biological food preservative. Specifically, nisin is antagonistic to spore-formers (Hurst, 1972).

## ACKNOWLEDGEMENT

Thanks to Dr. N. Olasupo of Lagos State University for purified nisin.

## REFERENCES

- Ademuyiwa OO (1995). Screening for nisin-producing *Lactococcus lactis* isolated from milk and milk products. MSc dissertation, Department of Botany and Microbiology, University of Ibadan, Nigeria. p. 87.
- Ahn C, ME, Stiles (1990). Plasmid-associated bacteriocin production by a strain of *Carnobacterium pisciola* from meat. *Appl. Environ. Microbiol.* 56: 2503-2510.
- Akinyanju JA (1989). Characteristics and production process of nuno: A Nigerian fermented milk food. *Chemie Microbiologies Technologie der lebensmitteld.* 12: 14-19.
- Aworh OC, Egunleti M (1985). Preservation of West African soft cheese by chemical treatment. *J. Dairy Res.* 52: 189-195.
- Bail O (1929). *Ergebnisse experimenteller Populations forschung.* *Immun. Forsch* 60: 1.
- Barry AL (1986). Procedure for testing antimicrobial agents in agar media: Theoretical considerations. In: (V. Iorlan Editor). p. 1. *Antibiotics in laboratory medicine*, 2<sup>nd</sup> ed. Williams and Wilkins, Baltimore, Md. USA.
- Benkerroum N, Ghouati Y, Sandine WE, Tantaout-Elaraki (1993). Methods to demonstrate the bactericidal activity of bacteriocins. *Lett. Appl. Microbiol.* 17: 78-81.
- Bernard A, Ferda M (1991). *Biochemical engineering and biotechnology handbook*. 2<sup>nd</sup> ed. Stockton Press New York, USA. pp. 67-68.

- Bhunia A, Ray KJ, Kalchayanand N (1991). Mode of action of pediocin ACH from *Pediococcus acidilactici* H on sensitive bacterial strains. *J. Appl. Bacteriol.* 70: 25-33.
- Bizani D, Brandelli A (2002). Characterization of a bacteriocin produced by a newly isolated *Bacillus* sp. Strain 8 A. *J. Appl. Microbiol.* 93: 512-519.
- Bouttefroy AA, Linder, Millière JB (2000). Predictive models of the combined effects of curvaticin 13, NaCl and pH on the behaviour of *Listeria monocytogenes* ATCC 15313 in broth. *J. Appl. Microbiol.* 88: 919-929.
- Corsetti A, Settanni L, Van Sinderen (2004). Characterization of bacteriocin-like inhibitory substances (BLIS) from sourdough lactic acid bacteria and evaluation of their in vitro and in situ activity. *J. Appl. Microbiol.* 96: 521-534.
- DE Man JC, Rogosa M, Sharpe ME (1960). A medium for the cultivation of lactobacilli. *J. Appl. Bacteriol.* 23: 130-135.
- DE Martins ECP, Franco DGM (1998). Inhibition of *Listeria monocytogenes* in a pork product by a *Lactobacillus sakei* strain. *Int. J. Food Microbiol.* 42: 119-126.
- DE Vuyst L, Vandamme EJ (1991). Microbial manipulation of nisin biosynthesis and fermentation. In: Nisin and novel lantibiotics (Jung G, Sahl HG (Editors). pp.398-409. ESCOM Science Publishers, Leiden, The Netherland.
- DE Vuyst L, Vandamme J (1992). Influence of the carbon source on nisin production in *Lactococcus lactis* subsp. *Lactis* batch fermentations. *J. Gen. Microbiol.* 138: 571-578.
- DE Vuyst L, Vandamme EJ (1993). Influence of the phosphorus and nitrogen source on nisin production in *Lactococcus lactis* subsp. *Lactis* batch fermentations using a complex medium. *Appl. Microbiol. Biotechnol.* 40: 17-22.
- Delve-Broughton J (1990). Nisin and its uses as a food preservative. *Food Technol.* 44: 100-112.
- Fernández AN, Horn MJ, Gasson HM, Dodd, Rodríguez JM (2004). High-level coproduction of the bacteriocins nisin A and lactococcin A by *Lactococcus lactis*. *J. Dairy Res.* 71: 216-221.
- Flores, S.H. and R.M. Alegre, 2001. Nisin production from *Lactococcus lactis* ATCC 7962 using supplemented whey permeate. *Biotechnol. Appl. Biochem.* 34: 103-107.
- Hurst A (1972). Interactions of food-starter cultures and food borne pathogens: the antagonism between *Streptococcus lactis* and spore-forming microbes. *J. Milk Food Technol.* 35: 418-420.
- Jack RW, Tagg JR, Ray B (1995). Bacteriocins of gram-positive bacteria. *Microbiol. Rev.* 59: 171-200.
- Jydegaard, AM, Gravesen A, Knochel S (2000). Growth condition-related response of *Listeria monocytogenes* 412 to bacteriocin inactivation. *Letters in Appl. Microbiol.* 31: 68-72.
- Leroy F, De Vuyst L (1999). Temperature and pH conditions that prevail during fermentation of sausages are optimal for production of the antilisterial bacteriocin sakacin K. *Appl. Environ. Microbiol.* 65: 974-981.
- Lindgren SW, Dobrogosz WJ (1990). Antagonistic activities of lactic acid bacteria in food and feed fermentations. *FEMS Microbiol. Rev.* 87: 149-164.
- Liu W, Hansen JN (1990). Some chemical and physical properties of nisin, a small-protein antibiotic produced by *Lactococcus lactis*. *Appl. Environ. Microbiol.* 56: 2551-2558.
- Mataragas M, Metaxopoulos J, E.H. Drosinos(2002). Characterization of two Bacteriocins produced by *Leuconostoc mesenteroides* L124 and *Lactobacillus curvatus* L442, isolated from dry fermented sausages. *World J. Microbiol. Biotechnol.* 18: 847-856.
- Matsusaki H, Endo N, Sonomoto K, Ishizaki A (1996). Lantibiotic nisin Z fermentative production by *Lactococcus lactis* IO-1: relationship between production of the lantibiotic and lactate and cell growth. *Appl. Microbiol. Biotechnol.* 45: 36-45.
- Mocquot G, Lefebvre E (1956). A simple procedure to detect nisin in cheese. *J. Appl. Bacteriol.* 19: 322-323.
- Morris CE (1991). Dairy ingredients boost shelf life, replace fat *Food Engr.* 63: 99-101.
- Nettles CG, Barefoot SF (1993). Biochemical and genetic characteristics of Bacteriocins of food-associated lactic acid bacteria. *J. Food Prot.* 56: 338-356.
- O'Sullivan L, Ross RP, Hill C (2002). Review: Potential of bacteriocin producing lactic acid bacteria for improvements in food safety and quality. *Biochimie.* 84: 593- 604.
- Ogunbanwo ST, Sanni AI, Onilude AA (2003). Characterization of bacteriocin produced by *Lactococcus plantarum* F1 and *Lactobacillus brevis* OG1. *Afr. J. Biotechnol.* 2: 219-227.
- Ogundiwin JO, Oke OL(1983). Factors affecting the processing of wara – a Nigerian white cheese. *Food Chem.* 11: 1-13.
- Ogundiwin JO (1978). A study of the traditional manufacturing processes and chemical composition of warankasi - a Nigerian white soft cheese. *Nig. Food J.* 2: 72-78.
- Olukoya DK, Tichacze PS, Butsch A, Vogel RF, Hammes P (1993). Characterization of the bacteriocins produced by *Lactococcus pentosus* DK7 isolated from ogi and *Lactococcus plantarum* DK9 from fufu. *Chem. Microbiol. Technol. Lebensm.* 15: 65-68.
- Raheem B (2006). Developments and microbiological applications in African foods: Emphasis on Nigerian wara cheese. PhD Dissertation, Department of Applied Chemistry and Microbiology, University of Helsinki, Finland. p.53.
- Ray B, Miller KW, Juan MK (2001). Bacteriocins of lactic acid bacteria. *India J. Microbiol.* 41: 1-21.
- Rayman K, Hurst A (1984). Nisin: properties, biosynthesis and fermentation. In *Biotechnology of industrial antibiotics*, (E.J. Vandamme, Editor). Marcel Dekker, New York. pp. 607-628.
- Risoen PA, Ronning P, Hegna IK, Kolsto AB (2004). Characterization of a broad range antimicrobial substance from *Bacillus cereus*. *J. Appl. Microbiol.* 964: 648-655.
- Rogers LA, Whittier EO (1928). Limiting factors in lactic fermentation. *J. Bacteriol.* 16: 11-14.
- Sanni AI, Onilude AA, Momoh MO (1999). Selection of starters and a starter-mediated novel procedure for production of Wara, a West African soft cheese. *Int. J. Food Sci. Tech.* 34: 325-333.
- Slorza-Feria J (2001). Study of the changes in cheese making parameters of skim milk with divalent cations addition. *Food Technol. Biotechnol.* 39: 115-121.
- Tagg JR, Mcgiver AR (1971). Assay system for bacteriocins. *Appl. Environ. Microbiol.* 21: 943-943.
- Van den Berghe, Skourtas E, Tsakalidou G, De Vuyst EL (2006) *Streptococcus macedonicus* ACA-DC 198 produces the lantibiotic, macedocin, at temperature and pH conditions that prevail during cheese manufacture. *Int. J. of Food Microbiol.* 107(2): 138-147.
- von Maydell HJ (1983). Arbres et arbustes du Sahel: Leurs caractéristiques et leurs utilisations Eschborn: Deutsche Gesellschaft für Technische Zusammenarbeit.
- Waters-Bayer A (1985). Dairying by settled Fulani women in central Nigeria and some implications for dairy development. A paper presented at a Pastoral Development Network luncheon talk given at Overseas Development Institute, London. p. 26.
- Yang R, Ray B (1994). Factors influencing production of bacteriocins by lactic acid bacteria. *Food Microbiol.* 11: 281-291.
- Zendo T, Fukao M, Ueda K, Higuchi T, Nakayama J, Sonomoto K (2003). Identification of the lantibiotic nisin Q, a new natural nisin variant produced by *Lactococcus lactis* 61-14 isolated from a river in Japan. *Biosci. Biotechnol. Biochem.* 67: 1616-1619.