Quality changes of stabilizer-free natural peanut butter during storage

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Abstract The storage stability of preservative-free peanut butter was evaluated for changes in physicochemical quality including moisture content and water activity, microbiological properties, oxidative stability and textural quality in terms of spreadability and firmness. The study was conducted for 16 weeks at storage temperature of 10, 25 and 35 °C on natural and pure peanut butter produced from two varieties of peanuts, the Virginia and Spanish TMV-2 varieties of China and India origin, respectively. The peanuts were ground using a high speed grinder for 2.5 and 3.0 min to produce peanut butter without addition of other ingredient. The natural peanut butter exhibited stability and had acceptable microbial count during storage. Storage at 10 °C gave similar textural quality with commercial product until week 8 and without apprecia-

ble loss in oxidative stability until week 12. At higher storage temperatures of 25 and 35 °C, oxidative stability was shortened to 4 weeks of storage. Among the factors of storage temperature and time, grinding time and peanut variety, storage temperature had the most significant effects on quality changes of natural peanut butter.

Keywords Natural peanut butter · Storage · Physicochemical properties · Microbial count · Oxidative stability · Textural quality

Introduction

Peanut butter is one of the nut butter or nut spread widely consumed at home and largely used in food related industry. Half of peanut production in the United States alone are processed into peanut butter (Suchoszek-Lukaniuk et al. 2011). The retained high protein and unsaturated fatty acids (UFA) content in peanut even after being processed into peanut butter makes it an excellent and affordable protein and lipid source. Peanut butter which contains approximately 27.8 % protein and 49.4 % lipid is an excellent source of energy (581 kCal/100 g) (Woodroof 1983). Due to its high nutritive value, peanut butter based ready-to-use therapeutic-food (RUTF) has been implemented in the diet program to treat malnutrition among children in African countries (Humphrey 2008, Israëls et al. 2009).

The demand and preference of natural food products is increasing over years (Carocho et al. 2014). Some consumers deliberately choose minimally processed foods over processed, and when processed food is chosen, they will select the ones with fewer additives and/or containing natural additives (Carocho et al. 2014). Peanut butter products are usually added with hydrogenated vegetable oil (HVO) such as mixture of hydrogenated rapeseed, cottonseed oil and soy bean

Research highlights 1. The natural peanut butter had acceptable microbial count during storage
2. Storage at 10 °C gave similar textural quality and storage stability with commercial product until week 8 and 12, respectively
3. Storage temperature had the most significant effects on quality changes of natural peanut butter
4. Natural peanut butter stored at 25 and 35 °C can be consumed within 48 h without major sensory concern
5. Satisfaction of quality attributes are different among storage temperature

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oils as stabilisers. The performance of hydrogenated palm oil however is not as good as the other HVO (Aryana et al. 2000; Gills and Resurreccion, 2000a; Gills and Resurreccion, 2000b). Natural peanut butter which is also called the “old fashioned” peanut butter is made purely from grounded roasted peanut into a fine paste is now getting back its popularity for its minimum process and additives because it has no or less than 1 % of salt added. Natural peanut butter was found to be preferable by 59 % of the respondent in a sensory evaluation test in terms of aroma and taste (How and Young 1985). In a different study by Gills and Resurreccion (2000a), the overall liking for HVO (mixture of hydrogenated rapeseed and cottonseed oils) stabilized peanut butter is the most preferred followed by natural peanut butter and then the palm oil stabilized. There were no significant differences in colour and flavour acceptance of natural peanut butter compared to those stabilized peanut butter with various HVO despite differences detected in its texture, oiliness, and spreadability between them (Gills and Resurreccion, 2000a).

Storage stability of peanut butter is the main concern for consumer acceptability due to its high polyunsaturated fatty acids (PUFA). Lipid oxidation is one of the most common testing for measurement of oxidative rancidity in oils and fats (Li et al. 2013) and the Peroxide Value (PV) is a measure of the concentration of peroxides and hydroperoxides formed in the initial stages. Storage stability of various butter and spread using PV as indicator has been applied for oilseed butter from sunflower kernels (Muttagi et al. 2014), peanut butter (El-Rawas et al. 2012) and shea butter (Honfo et al. 2011). Natural peanut butter is susceptible to oil separation due to absence of stabilizer. Oil separation leads to lipid peroxidation of peanut butter which develops the off-flavour and results in rancidity. Oil separation may also affect textural quality of peanut butter in terms of spreadability (Gills and Resurreccion, 2000a). Instrumental method of measuring spreadability using the texture analyzer was found to have good correlation with sensory assessment (Sanders III et al., 2014). Other peanut butter quality problems include those associated with food safety such as *Salmonella* outbreak (Burnett et al. 2000) and physicochemical attributes deterioration.

The objective of this work is to assess the effects of storage temperature, storage time, peanut variety and grinding time on storage stability by monitoring the moisture content, water activity, microbial count, peroxide value, oil separation and spreadability of stabiliser-free peanut butter.

Materials and methods

Natural peanut butter preparation

Two types of peanut butter used were the natural and commercial peanut butter. The natural peanut butters were

produced from peanuts imported from China (Virginia variety) and India (Spanish TMV-2 variety). 1 kg batch of peanuts were roasted in two aluminium trays ($14 \times 10 \text{ cm}^2$) in a convection oven (Memmert UNB 500, Germany) at 152°C -60 min and 158°C -45 min based on optimized roasting temperature and times (Mohd Rozalli et al. 2014).

After manual skin removal process, undamaged roasted peanuts were then subjected to grinding using ultra high speed grinder at 22,000 rpm (M-PLAN multi-function processor, M-PLAN Sdn. Bhd., Malaysia) for 2.5 and 3.0 min grinding time to produce natural peanut butter (Mohd Rozalli et al. 2015). The commercial smooth and spreadable peanut butter (Lady's Choice™, Unilever (Malaysia) Holdings Sdn. Bhd.) was purchased from a local hypermarket.

Storage condition and sampling

Twenty five grams of each peanut butter sample was filled into a polypropylene plastic container (3.5 cm height, 5.5 cm diameter) with lid, sealed tightly with petri film with $0.6 \pm 0.1 \text{ cm}$ headspace. The peanut butter samples were stored at three temperatures, $10 \pm 0.5^\circ\text{C}$, $24 \pm 1^\circ\text{C}$ and $35^\circ \pm 0.5^\circ\text{C}$ in a chiller (LabMart, Malaysia), in a small air-conditioned room of $3 \text{ m} \times 2 \text{ m} \times 3 \text{ m}$ and in an incubator (Incucell, MMM Med Center, Einrichtungen, GmbH), respectively to reproduce refrigerated, room and accelerated storage conditions. All samples were stored in dark to minimise light effects. Storage study was conducted in two batches for storage period of 16 weeks with analysis conducted at alternate weeks. Table 1 shows the sampling plan where first batch sampling started 1 week earlier than the second batch sampling. The overall conduct of experiment was 17 weeks where analysis was performed every week.

Moisture content analysis

Moisture content was determined following AOAC official method (AOAC 1996). Approximately 2 g of peanut butter from each sample was thinly spread on a pre-weighed metal moisture dishes (7 cm in diameter) and dried for 24 h at $100 \pm 5^\circ\text{C}$ in an oven (Memmert UNB 500). Covered dishes were placed in a desiccator for 30 min to reach ambient temperature. The moisture content (MC) was calculated based on the initial and final sample weights.

Water activity analysis

Peanut butter sample (2 g) was spread over the bottom of a sample cup and placed in a water activity meter (Aqua Lab, ModelCX-2, Decagon Devices, Inc., Pullman, WA, USA) to measure water activity (a_w).

Table 1 Sampling plan for 16 weeks storage studies of two batches of peanut butter

Week	Batch 1	Batch 2
0	√	N/A
1	X	√
2	√	X
3	X	√
4	√	X
5...	X...	√...
16	√	X
17	N/A	√

√ = sampling, X = no sampling, N/A = not available

Microbial analysis

Peanut butter samples were analyzed for the presence of viable microbial loads and Salmonella. 20 g of peanut butter samples were mixed with 180 ml 0.1 % peptone water (PW, Merck, Germany) at maximum speed of 18,000 rpm in a blender (Warring, Connecticut, USA). After mixing, 0.1 ml was withdrawn and plated either directly or after serial tenfold dilution, onto Tryptic Soy agar (TSA, BD/Difco Laboratories) for Salmonella detection and plate count agar (PCA) for aerobic and mesophilic bacteria using the total plate count method, in duplicates. The plates were incubated at 37 °C-24 h and 35 °C-48 h, respectively. After incubation, the colonies were counted, averaged and reported as colony form unit per gram of peanut butter (CFU/g). The total plate count was conducted following the FDA method (FDA 1998).

Peroxide value analysis

Indicators of lipid oxidation in peanut butter samples were measured by peroxide values (PV). PVs were quantified following the AOAC official method 965.33 (AOAC 1996). Approximately 25 g of peanut butter was extracted with hexane (HmbG Chemicals, German), filtered through Whatman#1 filter paper for 8 h in a Soxhlet extractor (Electrothermal, Britain). The solvent was then removed using a rotary evaporator (HeidolphLaborota 4001, Lohorota Instruments, Schwabach, Germany) to recover peanut oil. Peroxide value was then determined on 5 g of oil, using 0.01 N sodium thiosulfate (System, Malaysia) as the titrant (AOAC 1996). Data was expressed as milliequivalents of peroxide per kilogramme of sample (meq peroxide/kg sample).

Oil separation

Oil separation was observed daily but measurements were made every 2 weeks. Oil separation analysis was conducted following methods of Radočaj et al. (2012). Separated oil on the surface was absorbed using a filter paper and its

percentage was calculated based on the original weight of the samples. The amount of separated oil was determined as follow:

Oil separation (%)

$$= \left(\frac{\text{Weight of oil separated (g)}}{\text{Weight of peanut butter before separation (g)}} \right) \times 100 \quad (1)$$

Textural quality analysis

Textural quality was measured using the TTC Spreadability Rig attached to a texture analyzer (TA.XT_{plus}, Stable Micro Systems, Godalming, Surrey, U.K.) calibrated with a 5 kg load cell (Stable Micro Systems Ltd., Surrey, UK). The rig consists of male probe and female cone. Approximately 8 g of peanut butter samples was spread inside the female cone. The male probe penetrates into female cones from a fixed position of 25.0 mm at a speed of 10 mm/s. Firmness was expressed as maximum force (g) required for cone penetration. Spreadability value was indicated by the work of shear calculated based on the mean areas of the force versus time curves.

Statistical analysis

All analyses were performed in triplicates except for microbial analysis which was conducted in duplicates and reported as mean values ($\pm$ standard deviation). The vertical bars in all the symbols in the graphs represent standard deviation. Data from both batches was averaged and reported as final mean values ($\pm$ standard deviation). Data was analysed as function of variety, grinding time, storage temperature and storage time. One-way ANOVA and separation of means was analysed using Tukey's honestly significant differences test ($p < 0.05$) (Minitab 15.1, Minitab Inc., USA).

Results and discussion

Moisture content

The peanut butter sample exhibited moisture content increase below 2-fold during the storage period of 16 weeks (Fig. 1). The initial moisture content of all natural peanut butter was set to 1.6 ± 0.05 % by controlling the roasting process to ensure similar moisture content with commercial peanut butter. Increase in moisture content occurred in the 2nd week for natural peanut butter stored at 25 and 35 °C while those stored at 10 °C occurred after the 12th week. The moisture content of natural peanut butter of India peanuts was higher than the China peanuts at all storage temperature and time. The

commercial peanut butter showed better stability with moisture content changes within 1.64–2.07 %. Storage temperature and time have significant effect ($p < 0.05$) on moisture content increase. The increase of moisture content was also found in shea butter during storage of 2 months (Honfo et al. 2011) and in butter enriched with unsaturated fatty acids/conjugated linoleic acids (UFA/CLA) during storage of 8 weeks (Mallia et al. 2008). Following recommendations by Yang et al. (2013) on maximum shelf life of roasted almonds based on optimal moisture content range from 1.5–2.5 %, the natural peanut butter storage recommended for storage is beyond 16 weeks at 10 °C, and about 10 weeks at 25 and 35 °C where moisture content ranged from 1.6 to 2.5 %. Grinding time gave no significant effects on the moisture during the entire

storage while the India peanut variety generally has higher moisture contents.

Water activity

The water activity, a_w is seen increasing gradually but insignificantly at $p < 0.05$ during the storage period (Fig. 2). The average a_w for natural peanut butter from peanuts of China and India origin is 0.25 and 0.26, respectively. The a_w for commercial peanut butter is 0.29. The addition of additives and stabilizer contributes to the higher a_w of commercial peanut butter. Low and stable a_w is favourable to prevent microbial growth during storage. It was also reported in Burnett

Fig. 1 Moisture content changes in natural peanut butter samples produced at 2.5 and 3.0 min grinding time and commercial peanut butter during storage at a) 10 °C, b) 25 °C and c) 35 °C

Fig. 2 Water activity changes in natural peanut butter samples produced at 2.5 and 3.0 min grinding time and commercial peanut butter during storage at a) 10 °C, b) 25 °C and c) 35 °C

et al.'s (2000) work that a_w of regular peanut butter is higher than natural peanut butter, 0.29 versus 0.22. Only the storage time factor had significant impact on a_w of natural peanut butter ($p < 0.05$).

Microbial analysis

Peanut butter and other nut butter products are usually regarded as microbiologically stable and safe for consumption owing to the inherent low water activity between 0.22–0.30 as it cannot support the growth and proliferation of bacterial pathogens. The presence of *Salmonella* was not detected in all peanut butter samples during the 16 weeks of storage at all temperatures in this study. It is worthy to note that the survival rate of *Salmonella* in inoculated peanut butter is greater in commercial peanut butter than the natural's at all storage temperature due to the presence of added corn syrup solids, soy protein and nutrient supplements which helps in retaining viability of *Salmonella* (Burnett et al. (2000). In general, high fat, less carbohydrate content and higher storage temperature (21 °C) are effective methods for reducing *Salmonella* population in peanut butter (Burnett et al. 2000, He et al. 2011). Figure 3 shows that no microbial colony was observed during the first 2 months of storage period. The presence of microbes was observed at storage temperature of 25 and 35 °C starting from the 10th week whereas for the commercial peanut butter,

it was from the 16th week. Storage at 10 °C showed no colony was formed. These results indicate that storage temperature plays important role in bacteria growth in peanut butter. The bacterial count continues to increase until the 16th week of storage study. The slight increase in moisture content was suggested for the increase of microbial count in unsaturated fatty acids/conjugated linoleic acids (UFA/CLA) enriched butter (Mallia et al. 2008) which could be used to explain the increased microbial count during storage due to the increased moisture content (Fig. 1). Nevertheless, these natural peanut butters are safe to consume since the aerobic plate count is below the restriction limit of 10,000 cfu/g for peanut butter (USDA 2010). For dairy butter, the Swiss Federal Hygiene Regulation stated that microbiological count for dairy butter can be up to 10,000 cfu/g. Mallia et al. (2008) who produced treated and untreated dairy based butter of UFA/CLA stored for 6 weeks at 6 °C has conformed to the respective limits set. For shea butter, Codex Alimentarius's threshold is 1 cfu/g and Honfo et al.'s (2011) shear butter stored was safe up to 60 days at 30 °C. In general, storage at higher temperature was found to promote microbial growth in butter exceeding the restriction limit. The natural peanut butter of current study is safe even at storage temperature of 35 °C because of measured microbial count below 7900 cfu/g.

Peroxide value

Figure 4 shows the increase in Peroxide Value, PV during peanut butter storage from initial PV of 0.4 ± 0.04 meq peroxide/kg. The PV increased significantly with storage time except for samples stored at 10 °C and commercial peanut butter. Peroxide is the first product of oxidation of unsaturated fats/oils. During storage, peroxide formation is slow initially which is known as induction period and it varies from few weeks to several months depending on particular oil and temperature (Kirk and Sawyer 1991). As in the case of natural peanut butter in this study, the induction period might be less than 2 weeks because the PV increased dramatically after 2nd week of storage at all temperatures.

Peanut butter produced from 3.0 min grinding time exhibited higher PV than those at 2.5 min grinding time at all storage temperature especially after the 10th (10 °C) and 6th (25 and 35 °C) week. The higher PV of natural peanut butter of longer grinding time could be due to the greater exposure of lipid content susceptible to oxidation as result of higher surface to volume ratio of the peanut butter particles. Finer milled flaxseed particles contained more surface lipid and less internal lipid explained the 3 times higher PV than those with coarser particles after 48 days storage (Schomo et al. 2009). Woodroof (1983) demonstrated that coarser peanut butter had lower PV than finer peanut butter after 12 months storage at all storage temperature and the degree of difference reduced with temperature.

Fig. 3 Microbial presence in peanut butter samples during 16 weeks storage at **a)** 25 °C and **b)** 35 °C

Fig. 4 Change in peroxide values (PV) (milliequivalents of peroxide per kilogram sample) of peanut butter during storage at **a)** 10 °C, **b)** 25 °C and **c)** 35 °C. The horizontal bar in Fig. 4a represents the limit of PV in peanut butter following USDA regulations

The level of PV formation of natural peanut butter showed small difference between the 25 °C and 35 °C storage as indicated by mean differences (statistical analyses was not shown) but both were extremely higher than samples stored at 10 °C. At 10 °C, the kinetics of the peanut oil is suspended due to low temperature and is entrapped between peanut particles. A lower rate of oil separation and migration out of suspension caused less exposure to oxidation. Results on storage study of peanut paste of high oleic peanuts stored at 4, 23 and 40 °C also exhibited no significant difference in PV values between these three temperatures until day 140 whereas significant difference was observed for normal peanut paste

(Riveros et al. 2010). As the PV in this study was also significantly affected by peanut variety ($p < 0.05$) with the Spanish variety from India having higher PV than the Virginia variety from China regardless of grinding time and storage temperature, it is suggested that peanut varieties could give different impacts on PV during storage. Peanuts contains 45–49 % oil with 76–82 % of the peanut oil comprised of unsaturated fatty acids, of which 40–45 % are unsaturated oleic acid and 30–35 % are polyunsaturated linoleic acid (Woodroof 1983). The oleic acid (C18:1) is greater in Virginia peanuts (45.69 %) than in the Spanish variety (43.45 %) (Onemli 2012). The oxidative stability of peanut oil of high-oleic peanut was greater compared to peanut oil of normal peanuts (O’Keefe et al. 1993). Riveros et al. (2010) showed that peanut paste of high-oleic peanuts (78.5 % oleic acid) exhibited tremendous lower PV or higher oxidative stability than peanut paste of normal peanuts (45.8 % oleic acid).

The results clearly indicated storage time and temperature, grinding time and peanut variety have significant impact on oxidative stability in peanut butter. The PV increase in natural peanut butter reached maximum of 2.5, 75 and 80 meq peroxide/kg sample at 10, 25 and 35 °C respectively. Superior oxidative stability is achieved at 10 °C storage. With allowable PV limit in peanut butter of 1.5 meq peroxide/kg (USDA 2010), only natural peanut butter stored at 10 °C was found safe to consume until approximately week 12. PV in commercial peanut butter was below this limit until week 16 (10 °C) and week 12 (25 and 35 °C). It is therefore suggested to have peanut butter to be cold stored as a protection against oil separation and rancidity in summer even though this would affect the palatability of peanut butter (Woodroof 1983).

Oil separation

The peanut butter samples exhibited increase in oil separation during storage (Fig. 5). Oil separation was least at 10 °C storage with highest value of 0.35 %. Commercial peanut butter was stable throughout storage at all temperatures. Grinding time, peanuts variety and storage time had no significant influence on oil separation of natural peanut butter stored at 10 °C but not at higher temperatures of 25 and 35 °C. Samples from India peanuts have higher oil separation than the China peanuts and this supports the PV analysis where oxidative stability of natural peanut butter of India peanuts (Spanish var.) is lesser than China peanuts (Virginia var.). For the higher storage temperatures of 25 and 35 °C, oil separation was constant during the first 2 weeks and this supports the aforementioned 2 weeks’ induction period of peanut butter in this study. For storage at 25 °C, oil separation increased greatly between 2 weeks until the 10th week where it started to level off while for the 35 °C, oil separation continued increasing until 21 % oil separation. Gills and Resurreccion (2000b) recorded the

Fig. 5 Oil separation (%) of peanut butter during storage at **a)** 10 °C, **b)** 25 °C and **c)** 35 °C

highest oil separation of 14.8 % in unstabilized peanut butter after 153 days of storage at 30 and 45 °C.

Instant visual inspection of freshly prepared natural peanut butter after 48 h of storage reported no visible oil separation even at 35 °C storage. It is to ensure the oil is not readily separated upon processing. A minimum of 48 h after packing is required before consistency inspection being conducted on peanut butter (USDA 2011). Gills and Resurreccion (2000b) also reported similar observation for stabilized and non-stabilized peanut butter. USDA product regulations for peanut butter specify a maximum 1 ml of collectable free oil per 500 g of products for stabilized peanut butter whereas for non-stabilized peanut butter, the separated oil should be dispersed in 30–35 s by slight and moderate mixing upon inspection of

freshly manufactured product (USDA 2011). Hence it is a good indicator for natural peanut butter consumption within 48 h without major sensory concern.

Spreadability and firmness

Textural quality of peanut butter was measured by the amount of force (g) required to penetrate peanut butter as indicators for firmness and work of shear (g.sec) to reflect spreadability value. Work of shear was also used to measure spreadability of peanut skin fortified peanut butter (Sanders III et al. 2014), pistachio spread (Shakerardekani et al. 2013) and US commercial cream cheese (Brighenti et al. 2009). Work of shear is an opposite function of spreadability and penetration force is a direct function of firmness. Figures 6 and 7 show that

Fig. 6 Work of shear (g.sec) of natural and commercial peanut butter stored at **a)** 10 °C, **b)** 25 °C and **c)** 35 °C. The reciprocal of work of shear represents spreadability

Fig. 7 Penetration force (g) of natural and commercial peanut butter stored at **a)** 10 °C, **b)** 25 °C and **c)** 35 °C. Penetration force represents firmness

storage time has significant effect on spreadability and firmness of natural peanut butter ($p < 0.05$) respectively. Spreadability of natural peanut butter decreased as firmness increased over storage time as indicated by the increased work of shear and force. Both spreadability and firmness of peanut butter were the highest at 10 °C followed by 25 and 35 °C as shown by the significant effects of storage temperature on both attributes ($p < 0.05$). The spreadability and firmness of natural peanut butter is similar to the commercial peanut butter when stored at 10 °C until the 8th week before deviating sharply above the commercial peanut butter. At higher storage temperatures of 25 and 35 °C, higher spreadability and lower firmness was found in natural peanut butters than the commercial peanut butter within the first 3 and 6 weeks storage respectively.

At higher storage temperatures of 25 and 35 °C, work of shear for natural peanut butter was about 1.5 times lower than commercial peanut in the earlier weeks of storage. The work of shear of pistachio spread without emulsifier was about 6.0 times lower than the emulsifier formulated suggesting greater spreadability of non-emulsified product (Shakerardekani et al. 2013). Spreadability sensory profile from Gills and Resurreccion's (2000b) work showed that peanut butter which contained hydrogenated vegetable oil (HVO) was harder to spread on cracker than non-stabilized peanut butter. The addition of stabilizer creates a strong network between protein and fat resulted in spreadable but firmer peanut butter (Aryana et al. 2000). At 10 °C, the oil and fat content in peanut butter were hardening giving difficulty in penetration and spread. Aryana et al. (2000) showed a uniform distribution of protein bodies and cell wall fragments in the oil matrix of unstabilized peanut butter due to solidification of oil held peanut particles in suspension at 0 °C through their microstructure study. At other temperatures, the increase in work of shear and penetration force as function of time is due to oil separation occurrence during storage. Oil which act as lubricant is moving out from the peanut suspension system leaving the peanut solids layer to harden. Consequently, spreadability of natural peanut butter decreased whilst firmness increased as time increased. The results is in agreement with microstructure study by Aryana et al. (2000) who showed that the continuous oil phase was not associated with each protein component and cell wall fragment within the clump or aggregate of peanut solids. Therefore the incorporation of peanut oil within peanut particles in peanut butter complex system is crucial to ensure optimum textural quality of the products and stability.

Grinding time and peanut variety had no significant effect on spreadability and firmness at 10 °C storage. At 25 °C, there was significant difference in spreadability and firmness among grinding time but not between varieties. Contrary to the trend at 25 °C, peanuts variety has significant effect while grinding time has no significant effect on spreadability and firmness of natural peanut butter at 35 °C. Storage temperature and time was found to have more impact on spreadability and firmness of natural peanut butter than other attributes where spreadability is an increasing function of temperature and a decreasing function of storage time while firmness has the opposite trend.

Conclusion

The natural peanut butter produced had satisfactory physico-chemical quality, microbial safety but lacks in oxidative stability and textural quality. The oxidative stability was achieved within the first week at 25 and 35 °C storage and can be prolonged to 12 weeks at 10 °C storage. The textural

quality measurement was more superior than commercial samples when stored below 6 weeks at 25 and 35 °C, and similar to commercial sample at 10 °C storage up to 8 weeks. The product is stable in terms of a_w , which promotes product resistance towards microbial contamination. The oil separation analysis conformed to changes in PV, spreadability and firmness of natural peanut butter. Storage time and temperature gave more significant effect on the shelf life of natural peanut butter than grinding time and peanut variety which was dependent on storage temperature.

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References

- AOAC (1996) Official methods of analysis. Washington, D.C., Association of Official Analytical Chemists
- Aryana KJ, Resurreccion AVA, Chinnan MS, Beuchat LR (2000) Microstructure of peanut butter stabilized with palm oil. *J Food Process Preserv* 24(2000):229–241
- Brighenti M, Govindasamy-Lucey S., Lim K, Nelson K, Lucey JA (2009). Characterization of the rheological, textural, and sensory properties of samples of commercial US cream cheese with different fat contents. *J Dairy Sci* 91(12):4501–4517
- Burnett SL, Gehm ER, Weissinger WR, Beuchat LR (2000). Survival of *Salmonella* in peanut butter and peanut butter spread. *J Appl Microbiol* 89:472–477
- Carocho M, Barreiro MF, Morales P, Ferreira ICFR (2014). Adding molecules to food, pros and cons: A review on synthetic and natural food additives. *Compr Rev Food Sci Food Saf* 13(4):377–399
- El-Rawas A, Hvizdzak A, Davenport M, Beamer S, Jaczynski J, Matak K (2012). Effect of electron beam irradiation on quality indicators of peanut butter over a storage period. *Food Chem* 133:212–219
- FDA (1998). Bacteriological Analytical Manual. Chapter 3 (Edition 8, Revision A)
- Gills LA, Resurreccion AVA (2000a). Overall acceptability and sensory profiles of unstabilized peanut butter and peanut butter stabilized with palm oil. *J Food Process Preserv* 24(2000):495–516
- Gills LA, Resurreccion AVA (2000b). Sensory and physical properties of peanut butter treated with palm oil and hydrogenated vegetable oil to prevent oil separation. *J Food Sci* 65(1):173–180
- He Y, Guo D, Yang J, Tortorello ML, Zhang W (2011). Survival and heat resistance of *Salmonella enterica* and *Escherichia coli* O157:H7 in peanut butter. *Appl Environ Microbiol.* 77(23):8434–8438
- Honfo F, Hell K, Akissoé N, Coulibaly O, Fandohan P, Hounhouigan J (2011). Effect of storage conditions on microbiological and physicochemical quality of shea butter. *J Food Sci Technol* 48(3):274–279
- How JL, Young C (1985). Factors affecting peanut butter preference. *J Am Oil Chem Soc* 62(3):538–540
- Humphrey JH (2008). Underweight malnutrition in infants in developing countries: an intractable problem. *Arch Pediatr Adolesc Med* 162(7):692–694
- Israëls T, Borgstein E, Jamali M, De Kraker J, Caron HN, Molyneux EM (2009). Acute malnutrition is common in malawian patients with a wilms tumour: a role for peanut butter. *Pediatr Blood Cancer* 53(7):1221–1226
- Kirk RS, Sawyer R (1991). Pearson's composition and analysis of foods, 9th edn. Longman Sci Tech Harlow, pp 609–617
- Li H, Fan YW, Li J, Tang L, Hu JN, Deng ZY (2013). Evaluating and predicting the oxidative stability of vegetable oils with different fatty acid compositions. *J Food Sci* 78(4):H633–H641
- Mallia S, Piccinali P, Rehberger B, Badertscher R, Escher F, Schlichtherle-Cerny H (2008). Determination of storage stability of butter enriched with unsaturated fatty acids/conjugated linoleic acids (UFA/CLA) using instrumental and sensory methods. *Int Dairy J* 18(10–11):983–993
- Mohd Rozalli NH, Chin NL, Yusof YA (2014). Simultaneous multiple responses modelling, optimisation and correlation of asian type peanuts (*Arachis hypogaea* L.) roasting using response surface methodology. *Acta Aliment* 43(1):142–157
- Mohd Rozalli NH, Chin NL, Yusof YA (2015). Grinding characteristics of asian originated peanuts (*Arachis hypogaea* L.) and specific energy consumption during ultra-high speed grinding for natural peanut butter production. *J Food Eng* 152 (2015):1–7
- Muttagi G, Joshi N, Shadakshari YG, Chandru R (2014). Storage stability of value added products from sunflower kernels. *J Food Sci Technol* 51(9):1806–1816
- O'Keefe SF, Wiley VA, Knauff DA (1993). Comparison of oxidative stability of high and normal oleic peanut oils. *J Am Oil Chem Soc* 70(5):489–492
- Onemli F (2012). Impact of climate change on oil fatty acid composition of peanut (*Arachis hypogaea* L.) in three market classes. *Chil J Agric Res* 72(4):483–488
- Radočaj O, Dimić E, Vujasinović V (2012). Development of a hull-less pumpkin seed (*Cucurbita pepo*, L.) oil-press cake spread. *J Food Sci* 77(9):C1011–C1017
- Riveros CG, Mestrallet MG, Gayol MF, Quiroga PR, Nepote V, Grosso NR (2010). Effect of storage on chemical and sensory profiles of peanut pastes prepared with high-oleic and normal peanuts. *J Food Sci Agric* 90:2694–2699
- Sanders III CT, DeMasie CL, Kerr WL, Hargrove JL, Pegg RB, Swanson RB (2014). Peanut skins-fortified peanut butters: effects on consumer acceptability and quality characteristics. *LWT Food Sci Technol* 59(1):222–228
- Schorno AL, Mantney FA, Hall III CA (2009). Effect of particle size and sample size on lipid stability of milled flaxseed (*Linum usitatissimum* L.). *J Food Process Preserv* 34(2010):167–169
- Shakerardekani A, Karim R, Ghazali H, and Chin NL (2013). The effect of monoglyceride addition on the rheological properties of pistachio spread. *J Am Oil Chem Soc* 90(10):1517–1521
- Suchoszek-Lukaniuk K, Jaromin A, Korycińska M, Kozubek A (2011). Chapter 103 - health benefits of peanut (*Arachis hypogaea* L.) seeds and peanut oil consumption. In: Preedy VR, Watsons RR, Patel VB (eds) Nuts and seeds in health and disease prevention. Academic Press, San Diego, pp 873–880
- United States Department of Agriculture (2010). Commodity requirements PP12 peanut products for use in domestic programs, farm service agency (FSA), Washington, DC
- United States Department of Agriculture (2011). Grading manual for peanut butter, USDA, Washington, DC
- Woodroof JG (1983). Peanut Butter. In: JG Woodroof Peanuts: Production, Processing, Products. The AVI Publishing Company, Westport, Connecticut, pp 181–225
- Yang J, Pan Z, Takeoka G, Mackey B, Bingol G, Brandl MT, Garcin K, McHugh TH, Wang H (2013). Shelf-life of infrared dry-roasted almonds. *Food Chem* 138(1):671–678