European Journal of Nutrition & Food Safety

Volume 16, Issue 6, Page 45-54, 2024; Article no.EJNFS.116924
ISSN: 2347-5641

Sorption Isotherm and Effect of Packaging Materials on Proximate, Organoleptic and Lipid Oxidation Quality of Chicken Nuggets Stored at Two Different Temperatures

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ejnfs/2024/v16i61439

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here:
https://www.sdiarticle5.com/review-history/116924

Original Research Article

Received: 10/03/2024
Accepted: 14/05/2024
Published: 17/05/2024

ABSTRACT

The study Investigated sorption isotherm features and the effects of packaging materials of both high-density and low-density polyethylene on sensory properties, proximate composition and lipid oxidation of chicken nuggets in storage. Boneless chicken breast was procured from a reputable source and cut into sizeable weight of 50g each to produce the chicken nuggets used for the

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Cite as: *Alamuoye, O. F., Alamuoye, N. O., & Olowoyeye, J. C. (2024). Sorption Isotherm and Effect of Packaging Materials on Proximate, Organoleptic and Lipid Oxidation Quality of Chicken Nuggets Stored at Two Different Temperatures. European Journal of Nutrition & Food Safety, 16(6), 45–54. https://doi.org/10.9734/ejnfs/2024/v16i61439*

studies. The experimental setup for sorption isotherm analysis in this study involved using a gravimetric method to equilibrate the product at various relative humidity levels. Five (5g) grams of oven-dried chicken nugget samples of known moisture content were placed in a controlled humidity chamber, and the weight changes of the samples were monitored until equilibrium was reached. GAB equation was used to evaluate the product ware activity and monolayer moisture. Sensory assessment was evaluated using a 9- point hedonic scale while proximate composition of the chicken nuggets samples was determined according to the methods of the Association of Official Analytical Chemists. Thiobarbituric acid reactive substances (TBARS) assay was used to measure malondialdehyde (MDA) levels as a marker of lipid oxidation. The investigation showed that sensory qualities, proximate composition and lipid oxidation of chicken nuggets were markedly affected by the variance in temperature settings, with distinct disparities seen among different materials for packaging. Chicken nuggets stored at 25 0C caused a significant loss in organoleptic properties and some nutritional composition such as protein and fat. Storage of chicken nugget at 25 0C and 40 C showed a varied values in malondialdehyde as content ranged from 0.52 to 0.81 for chicken nugget stored at 250 C and 0.17 to 0.43 for the product stored at 40 C across the packaging materials investigated. The water activity and monolayer moisture results of sorption analysis revealed that good packaging materials of very low water vapour transmission rate should be used for storage of chicken nuggets as high-density polyethylene offered a promising alternative than low density polyethylene.

Keywords: Flavour; Malondialdehyde; polyethylene; proximate; Water activity; density polyethylene.

1. INTRODUCTION

Chicken nuggets, a famous fast-food item [1], present both nutritional benefits and loss concerns. Chicken nuggets are enjoyed by people of all ages, with various flavours and coatings available to suit different preferences. Despite their widespread availability and popularity, the sorption characteristics of the product need to be studied. Sorption isotherm is a critical concept in the field of food science and engineering [2], specifically in the study of moisture absorption by food products such as chicken nuggets. The understanding of this relationship between the equilibrium moisture content of a food product and the water activity of its surrounding environment is essential for predicting the shelf-life of food products, determining their stability, and optimizing their processing conditions [3,4]. By analyzing the sorption isotherm of chicken nuggets, valuable insights into the moisture sorption behavior of this popular food item, which can ultimately inform strategies for improving its quality and extending its shelf-life can be evaluated.

Chemical changes in food products can significantly impact their shelf-life stability, sensory attributes, and overall quality. In the case of chicken nuggets, various chemical reactions may occur during storage, leading to changes in flavor, texture, and nutritional content [5]. For example, lipid oxidation, protein denaturation, and maillard browning are common chemical processes that can occur in chicken nuggets over time, affecting their color, taste, and nutritional value [6]. Understanding some chemical changes of chicken nuggets in storage is crucial for designing appropriate packaging materials and storage conditions to extend their shelf-life and maintain product quality. Moisture migration have been reported to cause changes in texture which resulted in a loss of crispness and a decrease in overall quality [7]. Therefore, physical changes in chicken nuggets can occur during storage due to various factors such as moisture exchange, lipid oxidation, and protein denaturation.

Research has shown that sensory changes can also greatly impact the quality and shelf-life stability of food products such as chicken nuggets [8]. These sensory changes can occur due to various factors including oxidation, microbial growth, and storage conditions. As chicken nuggets age, they may experience colour changes, off-flavours, texture modifications, and a decrease in overall palatability. Understanding and monitoring these sensory changes is crucial for determining the shelf-life of chicken nuggets and ensuring consumer satisfaction. By studying sensory changes of chicken nuggets, researchers can gain valuable insights into the factors affecting their quality over time.

Previous studies on meat products have primarily focused on their nutritional content, sensory attributes, and production methods with limited information on its sorption characteristics and nutritional changes in storage. For example, a study by Alugwu et al. [9] investigated the effect of different frying techniques on the nutritional quality of chicken breast meat. They found that air frying chicken breast meat resulted in higher cooking yield and lower fat content than when deep fat frying method.

Stability determinants in processed foods play a crucial role in maintaining product quality and safety over an extended period [10]. Factors such as water activity, pH, packaging materials, storage conditions, and microbial contamination can significantly impact the stability of processed foods [11]. It is essential to understand the interactions between these determinants in order to establish effective shelf-life prediction models for specific food products. Packaging plays a critical role in influencing the shelf-life of food products by protecting them from external factors such as moisture, oxygen, light, and microbial contamination [12,13] and this phenomenon can help optimize packaging design to extend the shelf-life of chicken products. Packaging materials come in different thickness, with varied moisture barrier properties, packaging materials with high thickness can enhance the preservation of texture and flavor of the chicken nuggets [14]. Therefore, investigating the influence of packaging on the shelf-life of chicken nuggets is essential for ensuring the quality and safety of the product for consumers.

The research objectives of this study are twofold. Firstly, the study aims to determine the equilibrium sorption isotherm of chicken nuggets to understand the moisture absorption behavior of the product.

Secondly, the study seeks to investigate the effect of packaging materials on the shelf-life of chicken nuggets by analyzing the changes to nutritional composition sensory characteristics and lipid oxidation in storage. By achieving these objectives, this research will contribute to the understanding of the factors influencing the shelf-life of chicken nuggets and provide valuable information for improving the product's packaging and storage practices

2. MATERIALS AND METHODS

2.1 Preparation of Chicken Nuggets

1000g of boneless chicken breast was procured from Bolab Farm, Ado Ekiti, Nigeria. This was cut into sizeable weight of 50g each, dried ingredients for coating were measured into a separate mixing bowl; 100g of all-purpose flour, 1g of common salt, 2g of garlic powder, 1g of ginger powder, 2g of guava leaf powder, 2g of bitter leaf powder, 1g of oregano, 1g of baking powder and 2g of chili pepper. 2 large table size eggs were cracked, beaten and used as a binder. Each chicken cut was dipped into the beaten eggs, pressed into the flour containing all ingredients and allowed to be coated properly. Excess flour was shaken off. Coated chicken cuts were fried with canola oil in a large skillet in batches at temperature of 180^{o}C and cooked until 72^{o}C internal temperature was obtained using meat thermometer. This procedure was repeated three more times to produce enough products for triplicate experiment to be made possible.

2.2 Procedure of Adsorption

The experimental setup for sorption isotherm analysis in this study involved using a gravimetric method to determine the water sorption behavior of chicken nuggets at various equilibrium relative humidity levels. Five (5g) grams of oven-dried chicken nugget samples which initial moisture content have been determined were placed in a controlled humidity chamber, and the weight changes of the samples were monitored until equilibrium was reached. The sorption isotherm data obtained from this experimental setup were then fitted to GAB mathematical model to evaluate the sorption behavior of chicken nuggets. The determination of the equilibrium moisture content was carried out by oven dry method, the sample was dried at 105 °C for 24 h. All the experiments were carried out in triplicate. Nine saturated salt solutions prepared ranged between 0.043 to 0.979. The water activities and the salt solutions used were as reported [15] and this is as given in Table 1. For the chicken nugget to attain equilibrium moisture content, the experiment was set at 15°C.

Table 1. Saturated salt solution used for sorption studies

Salt	aw (15^{0}C)
Cesium Flouride	0.043
Lithium Chloride	0.113
Potassium Acetate	0.234
Magnesium Chloride	0.333
Potassium Carbonate	0.432
Sodium Bromide	0.607
Sodium Chloride	0.756
Potassium Chloride	0.859
Potassium Sulfate	0.979

2.2.1 Determination of water activity and monolayer moisture

Water activity and monolayer moisture value of the product were determined according to GAB equation [16] which was rearranged into second degree polynomial for the determination of water activity and monolayer.

$$\text{GAB Equation} = = \frac{M}{Mm} = \frac{ABaw}{(1-Baw)(1-Baw+ABaw)} \quad [17] \quad \text{Eq. (1)}$$

$$\text{Mo – Monolayer value} = 1/\sqrt{b^2} - 4ac \quad \text{Eq. (2)}$$

$$a_w = a_w/M = \text{Equation of line=y} \quad \text{Eq. (3)}$$

2.2.2 Determination of equilibrium moisture content

Determination of equilibrium moisture content was carried out as stated below:

$$\text{EMC} = \frac{We}{Wi}(\text{Mi}+1) - 1 \quad [18] \quad \text{Eq. (4)}$$

where We is the equilibrium weight of the sample (g), Wi is the initial weight of the sample (g), and Mi is the initial moisture content of the sample (g)

2.3 Sensory Evaluation of Chicken Nuggets

The sensory assessment was evaluated using a 9- point hedonic scale ranked as follows; like extremely to very much (8–9 scores), like moderately to like slightly (5–7 scores), neither like nor dislike to dislike slightly or dislike moderately (2–4 scores) and dislike extremely to dislike very much (0–1 score) for, tenderness, texture, aroma, flavor and over all- acceptability. A ten member of semi-trained taste panelist of both sexes were engaged in the assessment of sensory properties of this product. The assessors were placed in an individual unit cell and each person was given unsalted biscuits and fresh orange juice to cleanse palate after each taste of the sample. Samples were coded and independently evaluated [19].

2.4 Proximate Composition Determination of Chicken Nuggets

The proximate composition of the chicken nuggets samples was determined according to the methods of the Association of Official Analytical Chemists (AOAC). All analyses were conducted in triplicate to ensure reliability [20].

2.5 Lipid Oxidation

Malondialdehyde (MDA) levels as a marker of lipid oxidation was measured with thiobarbituric acid reactive substances (TBARS) assay [21].

2.6 Stability Assessment

Chicken nuggets used for stability assessment was packaged in four different packaging materials. Thirty (30g) of chicken nugget sample were weighed into packaging materials of 10cm X10cm size. The packaging materials used for this study included high-density polyethylene (HDPE) of 10µm and 20µm thickness and low-density polyethylene (LDPE) of 10µm and 20µm thickness. These were stored in the refrigerator at 4^0 C and ambient temperature of 25^0 C with the aid of an incubator for 30 days.

2.7 Statistical Analysis

Statistical analysis was carried out using IBM SPSS Statistics 20, One-way ANOVA Post Hoc Multiple Comparisons of Ryan-Einot-Gabriel-Welsch F’ test at 0.05 significance level [22].

3. RESULTS AND DISCUSSION

Fig. 2 showed the sample of freshly produced chicken nuggets used for these studies. The result interpretation of the equilibrium sorption isotherm and shelf-life stability of chicken nuggets study revealed that the product exhibited type IV isotherm behavior, which provides valuable insights into the adsorption behavior of water onto chicken nuggets. The obtained data show that the adsorption process follows a typical monolayer adsorption mechanism, where water molecules form a multilayer on the surface of the nuggets. This type of isotherm is often observed in porous materials with heterogeneous surfaces, where the formation of multiple layers of adsorbates takes place [23]. The equilibrium moisture content of chicken nuggets ranged from 25.36% to 71.25%, covering a range of 0.043 to 0.979 water activity respectively, suggesting a relatively high-water content. The shelf-life stability assessment indicated that chicken nuggets stored at 4°C maintained an acceptable quality for up to 30 days, based on sensory evaluation and moisture content analysis. These findings suggest that equilibrium sorption isotherms and shelf-life stability are crucial factors to consider in the formulation and storage of chicken nuggets to ensure product quality and consumer satisfaction.

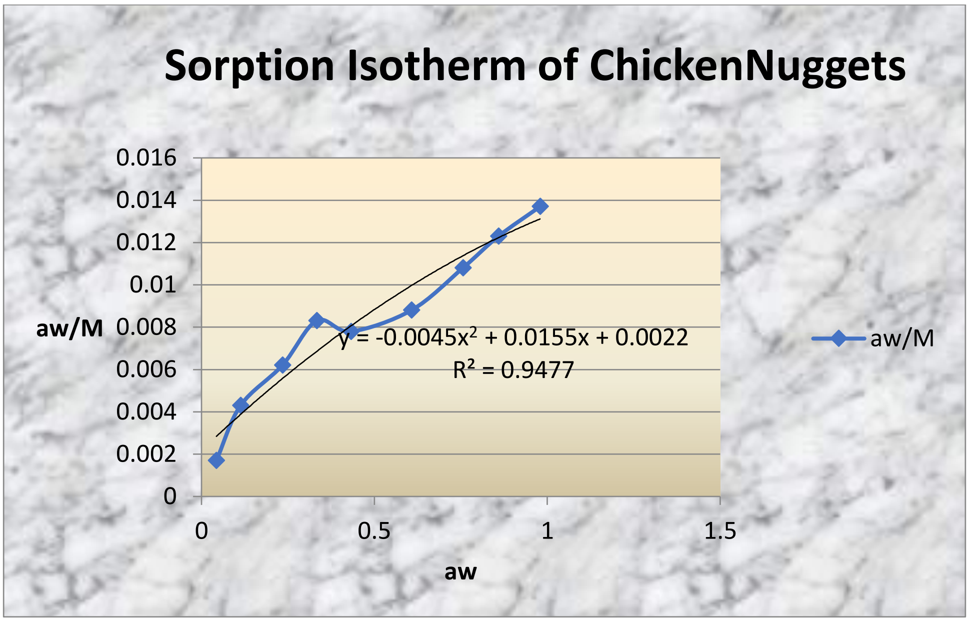

Fig. 1. Adsorption Isotherm Curve of Chicken Nuggets

The monolayer value of 59.77 (g H_2O / g Solid) for chicken nugget falls in the region C of sorption isotherm where water is known to be loosely bond to chicken nugget with much water held in large capillaries. This water may be much available for chemical reaction, microbial spoilage especially if this product is stored at 0.1 above its water activity. Additionally, the shelf-life stability studies at 25^0 C demonstrate that the moisture content of the nuggets was affected over time, indicating that the product may not be too stable under ambient storage temperature. These findings on sorption isotherm have several implications for food industry. Understanding the sorption isotherms of chicken nuggets can aid manufacturers in designing appropriate packaging materials and storage conditions to maintain product quality and extend shelf-life. By determining the equilibrium moisture content at different relative humidities, producers can optimize packaging materials to prevent moisture migration and reduce the risk of microbial growth or lipid oxidation. These insights can also help the food industry ensure the safety and sensory attributes of chicken nuggets throughout their distribution and consumption.

Table 2. Sorption Isotherm of Chicken Nuggets

aw (15^0C)	EMC	aw/M
0.043	25.36	0.0017
0.113	26.34	0.0043
0.234	37.62	0.0062
0.333	40.32	0.0083
0.432	55.15	0.0078
0.607	69.36	0.0088
0.756	69.55	0.0108
0.859	70.13	0.0123
0.979	71.25	0.0137

EMC- Equilibrium moisture content, a_w- Water activity, a_w/M- Water activity of moisture

Table 3. Analysis of sorption data of Chicken Nuggets according to GAB Model

Product sample	Water activity (a_w)	Monolayer value (Mo) (g H_20/g Solid)	R^2 (Fitness of curve)
Chicken Nuggets	0.5759	59.77	0.947

Table 4. Sensory properties of fresh fried chicken nugget and effects of packaging materials on sensory properties of chicken nugget stored at different temperatures for 30 days

Packaging materials	Sensory properties of chicken nugget stored at 4 ^{0}C					Mean + SEM	Sensory properties of chicken nugget stored at 25 ^{0}C					Mean + SEM
	Ar	**Fl**	**Tx**	**Tend**	**OA**	**Ju**	**Ar**	**Fl**	**Tx**	**Tend**	**OA**	**Ju**
HDPE (20µm)	8.17 ±0.31^c	7.67 ±0.2^b	7.50 ±0.34^c	5.50± 0.22^a	6.83 ±0.31^b	6.28 ±0.00^d	6.17 ±0.31^c	5.67 ±0.21^b	5.50 ±0.34^c	3.50 ±0.22^a	4.83 ±0.31^b	5.18 ±0.00^d
HDPE (10µm)	6.83 ±0.31^b	5.50 ±0.22^a	6.00 ±0.37^b	5.16 ±0.31^a	6.50 ±0.22^b	6.03 ±0.03^c	4.83 ±0.31^b	3.50 ±0.22^a	4.00 ±0.37^b	3.17 ±0.31^a	4.50 ±0.22^b	5.04 ±0.04^c
LDPE (20µm)	5.67 ±0.33^a	5.00 ±0.26^a	5.33 ±0.21^{ab}	4.83 ±0.31^a	5.33 ±0.21^a	5.55 ±0.03^b	3.67 ±0.33^a	3.00 ±0.26^a	3.33 ±0.21^{ab}	2.83 ±0.31^a	3.33 ±0.21^a	4.46 ±0.02^b
LDPE (10µm)	5.33 ±0.21^a	4.67 ±0.33^a	4.50 ±0.34^a	4.66 ±0.33^a	5.17 ±0.31^a	5.11 ±0.00^a	3.50 ±0.22^a	2.67 ±0.33^a	2.50 ±0.34^a	2.67 ±0.33^a	3.17 ±0.31^a	4.12 ±0.01^a
	Sensory properties of fresh fried chicken nugget											
	Ar		**Fl**		**Tx**		**Tend**		**AO**		**Ju**	
	7.33±0.42		7.17±0.54		6.17±0.48		6.17±0.48		7.5±0.56		6.33±0.37	

SEM- Standard error of mean, Ar- Aroma, Fl- Flavour, Tx- Texture, Tend- Tenderness, OA- Overall acceptability, Ju- Juiciness, HDPE- High density polyethylene, LDPE- Low density polyethylene

Table 5. Proximate composition of fresh fried chicken nuggets and effects of packaging materials on proximate composition of chicken nugget stored at different temperatures for 30 days

Packaging materials	Proximate composition of chicken nugget stored at 4 ^{0}C					Proximate composition of chicken nugget stored at 25 ^{0}C				
	Protein	**Fat**	**Ash**	**MC**	**CHO**	**Protein**	**Fat**	**Ash**	**MC**	**CHO**
HDPE (20µm)	48.53 ±0.01^b	6.08 ±0.01^a	4.32 ±0.12^d	37..75 ±0.012^c	3.41 ±0.01^d	46.43 ±0.01^d	5.66 ±0.01^d	7.11 ±0.01^a	35.41 ±0.01^a	5.39 ±0.01^a
HDPE (10µm)	48.49 ±0.01^a	5.98 ±0.01^b	4.82 ±0.01^c	36.87 ±0.01^d	3.84 ±0.01^c	44.11 ±0.01^c	5.42 ±0.10^c	8.71 ±0.01^b	33.78 ±0.01^b	7.98 ±0.01^b
LDPE (20µm)	48.21 ±0.00^c	4.88 ±0.01^c	6.70 ±0.01^b	35.89 ±0.00^b	4.32 ±0.01^b	43.12 ±0.00^b	3.91 ±0.00^b	10.98 ±0.01^c	32.34 ±0.00^c	9.65 ±0.00^c
LDPE (10µm)	47.10 ±0.01^d	4.53 ±0.01^d	7.12 ±0.00^a	35.33 ±0.01^a	4.65 ±0.01^a	42.33 ±0.12^a	3.43 ±0.01^a	11.83 ±0.00^d	31.62 ±0.01^d	10.79 ±0.01^d
	Proximate composition of fresh fried chicken nuggets									
	Protein Mean ± SEM		**Fat Mean ± SEM**		**Ash Mean ± SEM**		**MC Mean ± SEM**		**CHO Mean ± SEM**	
	48.67±0.33		6.17±0.00		3.83±0.33		38.07±0.00		3.43±0.33	

SEM- Standard error of mean, MC- Moisture content, CHO- Carbohydrate, HDPE- High density polyethylene, LDPE- Low density polyethylene

Table 6. Oxidative stability of fresh fried chicken nugget and effects of packaging materials on lipid oxidation of chicken nugget stored at different temperatures for 30 days

Packaging materials	Lipid oxidation at 4 ^{0}C	Lipid oxidation at 25 ^{0}C
	TBARS (MDA/Kg meat)	TBARS (MDA/Kg meat)
HDPE (20µm)	0.17 ± 0.00^{b}	0.52 ± 0.00^{a}
HDPE (10µm)	0.22 ± 0.01^{b}	0.56 ± 0.00^{b}
LDPE (20µm)	0.24 ± 0.10^{ab}	0.64 ± 0.00^{c}
LDPE (10µm)	0.43 ± 0.00^{b}	0.81 ± 0.00^{d}
Oxidative stability of fresh fried chicken nugget		
	0.17±0.00	

HDPE- High density polyethylene, LDPE- Low density polyethylene, TBARS- Thiobarbituric Acid-Reactive Substance, MDA- Malondialdehyde

Fig. 2. Sample of freshly produced chicken nugget

The effects of packaging materials on the proximate composition of chicken nuggets stored at different temperatures for 30 days provided valuable insights into the impact of packaging on food composition quality [24]. The results indicate that the type of packaging material used can significantly affect the composition of chicken nuggets, with clear differences observed in terms of moisture content, protein levels, and lipid oxidation. Also, the storage temperature plays a crucial role in determining the rate of deterioration of chicken nuggets, highlighting the need for careful consideration when selecting packaging materials for food products [25].

The results of lipid oxidation of chicken nuggets during storage at 4^0 C and 25^0 C for an extended period of 30 days showed that the type of packaging and temperature can greatly influence the rate of lipid oxidation. Chicken nuggets stored in high-density polyethylene packaging materials at 4°C, had their lipid oxidation levels significantly lower compared to those stored in low-density polyethylene packaging materials at the same temperature [26]. However, at 25°C, the differences in lipid oxidation levels between the packaging materials were pronounced. Low density polyethylene (10µm) packaging recorded the highest values of 0.43 and 0.81 of lipid oxidation at 4^0 C and 25^0 C respectively. This observation may be due the fact this packaging material may not be as strong as high-density polyethylene packaging materials in prevention of moisture and oxygen migration [27, 28]. This suggests that the type of packaging material plays a crucial role in maintaining the lipid quality of the chicken nuggets.

The result of sensory properties of chicken nuggets stored at 4^0 C and 25^0 C for 30 days showed that that the type of packaging materials and storage temperatures significantly influenced the sensory attributes of the chicken nuggets in storage. Spoilage of organoleptic compositions, such as changes in flavor and odor, had been reported to commence even before microbiological spoilage in foods [29]. It was also observed that certain packaging materials helped maintain the quality of the product, while others led to a deterioration in sensory properties. Storage at 4^0C where oxidation was reduced, the sensory properties were more preserved compared to storage at 25^0 C where degradation accelerated [30]. Therefore, selecting appropriate packaging materials tailored to specific storage conditions is essential in preserving the sensory quality of chicken nuggets in storage [31,32].

4. CONCLUSION

In conclusion, the choice of packaging materials is a significant factor in keeping the quality of chicken nuggets during storage as this can have varying effects on the sensory attributes, proximate composition and lipid oxidation of chicken nuggets over time. High-density polyethylene which showed the most favorable outcomes in terms of maintaining product quality and storage at 4^0 C which preserved the quality of this product are to be of great consideration for the long-term storage of chicken nuggets.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/116924