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FORMALDEHYDE, A FOOD ADDITIVE AS PRESERVATIVES: ITS APPLICATIONS AND HEALTH IMPLICATIONS– A REVIEW

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ABSTRACT

Food additives have been used in food processing from time immemorial. Their applications in food are used to enhance certain qualities such as appearance, texture, flavour or extend the shelf life of foods as food preservation. Food preservatives have wide applications in food industry due to their ability to extend shelf life and hence boost food processors' income. In view of the advantages, there are enormous food preservatives in the market which have been used appropriately by food handlers while some have abused their uses by going out of the regulated acceptable dose or using the prohibited one. Among the preservatives that have been unscrupulously used is formaldehyde. This study, therefore, appraises the current use of formaldehyde, its health implications, and possible way out for its safe applications. Formaldehyde is a simple chemical compound derived from hydrogen, oxygen and carbon. Formaldehyde naturally occurs in varieties of food items, such as fruits, meats, fish, crustaceans and dried mushrooms. It has antimicrobial and antioxidant properties that can retard spoilage, uphold product quality and safety as well as extends the storage shelf life. Hence, it is permissible exclusively as additives in some sea foods such as fish, crayfish. The use of synthetic form: aldehyde, in food processing and storage must be under regulations to ensure the safety of consumers and end users of the product.

KEYWORDS: Formaldehyde, safety, preservation, shelf life, regulations, safety.

1.0 INTRODUCTION

Food is such a substance that is liable to spoilage due to chemical, enzymatic or microbial activities, either within the food itself or from the surrounding environmental factors, hence, the shelf life of food is reduced or the quality is compromised (Esteso *et al.*, 2021). Food product quality is important in determining the acceptability and price value (Aschemann-Witzel *et al.*, 2017; Duan and Liu, 2019). In the meantime, the recent surge in world population calls for food products to be preserved stored and delivered from one place to another place (Hammond *et al.*, 2015). Prolonged storage of food products can reduce sensory qualities such as texture, taste and appearance and decrease their nutritional values significantly; hence, preservatives are added to foods to prevent spoilage. Thus, the application of food preservatives in foods is the effort put forward to secure and preserve foods' wholesomeness till it reaches the consumers or expires (Surahman *et al.*, 2017). Among such preservatives are the sulphites, benzoates and sorbates which are referred to as synthetic preservatives while natural food preservatives include salts, sugar, essential oils, vinegar and ethanol. Furthermore, natural preservatives are easy to obtain since the sources are from plants, animals and microbial origin (Surahman *et al*., 2017; Nowshad *et al*., 2018).

Formaldehyde in its natural form exist as organic chemical substance that is found in foods with the chemical formula CH_2O and structure as shown in Figure 1. Formaldehyde is a simple chemical compound made of hydrogen, oxygen and carbon. Therefore, there is synthetic form of this chemical substance, which is produced industrially by the catalytic oxidation of methanol. But it is naturally found in wide varieties of food items, such as fruits, meats, fish, crustaceans and dried mushrooms, thus acting as a natural preservative. This preservative has antimicrobial and antioxidant properties that can retard spoilage; uphold product quality and safety as well as extend the storage shelf life. Hence, it is permissible as additives in some sea foods such as fish, crustaceans and other seafood as synthetic additives (Hussain *et al.*, 2021; Roxana–Gabriela, 2019). The occurrence of formaldehyde is found as a natural common metabolic by-product notably in pear, apple, green onion and mushrooms (Jung *et al*., 2021). In plant and animal metabolic processes, formaldehyde is generated from deferent methylated compounds by demethylases, and from inter-conversion of glycine and serine that is catalyzed by pyridoxal phosphate. The presence of this natural formaldehyde may interfere with detecting artificially added formaldehyde in foods (Anand and Sati, 2013; Olatunde and Benjakul, 2018).

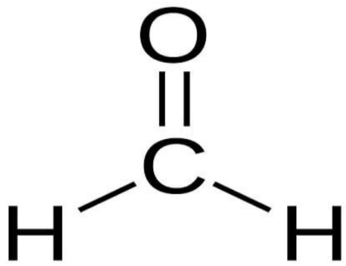

Figure 1: Structure of Formaldehyde (CH2O).

In recent years, synthetic formaldehyde is reported to be widely used as a food preservative to increase the shelf life of fruits and fish in tropical countries. Formaldehyde is detrimental to human health when taken above the permissible level. Hence, the use of synthetic formaldehyde as a food preservative is legally prohibited in most countries (Nowshad *et al.*, 2018). Formaldehyde is a basic component of most raw materials used in producing items such as plastics, wooden boards, and tin plates used in food packaging, likewise, the use of synthetic formaldehyde as a preservative has been documented (Silva and Lidon, 2016).

In sugar production industry, formaldehyde is used as a preservative to prevent infection (Silva and Lidon, 2016) and inhibit the growth of microorganisms. It is used in production of sugar syrup and juice, preservation of dried foods, disinfection of containers, preservation of fishes and certain oils and fats; it is also used in the modification of starch for cold swelling, which is useful in textile industry. Formaldehyde can be introduced into food through cooking and especially through smoking of food, from utensils and as a combustion product; it can be eluted from formaldehyde-resin plastic dishes with water, acetic acid, and ethanol in amount directly proportional to the prevailing environmental temperature (WHO, 1988; Roxana-Gabriela, 2019). Application of formaldehyde in fishes has been a major issue of concern. Consumer increasing demand for fresh fish products has led to an increase in the use of the synthetic formaldehyde additive for preservation, in order to make fishes available in fresh form all the year round to ensure food security. Those factors that contribute to the increase use of formaldehyde include the need to keep fish fresh after fishing at a far distance from the storage facilities, lack of cooling storage infrastructure for transportation and lack of appropriate policy on monitoring (Melnyk and Yanenko, 2015; FAO, 2017),

There are many factors which can influence the quality of food products; one of the vital factors is maintaining products in a predetermined temperature through the life cycle in storage, since it can slow down the growth of microorganisms which deteriorate food quality.

Cold storage has been used together with impregnation of formaldehyde (formalin) to the surface of fish, frozen chicken and meat to keep them fresh at the retailer's shops (Gharehyakheh *et al.*, 2019). Formaldehyde has found wide applications, most times being abuse, in consumer goods and other products that are use in transporting foods from the countries of origin to its final destinations. Many of the known additives like E240 and E900 contain formaldehyde as a component chemical (Suomi *et al*., 2018). Hence. Dimethylsiloxane also known as polydimethylsiloxane (PDMS) contains methyl form of formaldehyde used as antifoaming agent in food, with the European food additive number E900 which is listed in Commission regulation (EU) number 231/2012 as an authorized food additives (Melnyk and Yanenko, 2015). These additives are commonly used in frying oil due to its good defoaming quality at high temperature. This antifoaming agent is used in fruits and vegetable juice and also used as anti-caking agent in confectionaries and flour products (Suomi *et al*., 2018).

To protect citrus fruits during transportation some food additives such as E230, E231 are treated with formaldehyde and are used either directly on the fruits or on the wrapping packaging (Melnyk and Yanenko, 2015). The formaldehyde additions to consumer's good is intended to protect the product from spoilage by microbial contamination, though this action was admitted by some relevant authorities as misuse (Surahman *et al*., 2019). Consequence of the noted misuse had led to regulations of permissible maximum level of applications in some specific food products. The permissible maximum levels for certain foods are 10 mg/kg, 110 mg/ kg and 16 mg/kg for ready-to-eat, dry gelatin desert mixes and ready-to-serve desert, respectively (Table 1).

Formaldehyde is also used in household cleaning agents, dishwashing liquids, fabric softeners, shoe care agents shampoos and waxes, carpet cleaning agents and as a rule; its content ration should be less than 1 %. Any disinfecting cleaning agents containing high concentrations up to 7.5 % must be diluted before use. Formaldehyde is potent skin, eye and lung irritants and unregulated applications of this additive may pose high risk to the consumer (Nowshad et al., 2018).

Table 1: Formaldehyde as regulated preservative in food commodity.

Commodities	Permissible level	References
Beer	2 mg/l	MOH (2005).
Dry desert	110 mg/ kg	Wang *et* al., 2007; Wahed *et al.*, 2016
Fish	2 mg/kg	MOH (2005), Xuang *et al.* 2006
Fish (formalin)	15-250 mg/ml	Laly *et al.*, 2018
Fruits	2mg/kg (USEPA)	USEPA. 2010
Feed	2.5g/kg	USEPA. 2010
Food as daily intake	11 mg/kg	Wahed *et al.*, 2016
Gelling additives	50 mg/kg	Wahed *et al.*, 2016
Meat	2 mg /l	MOH (2005)
Ready-to-serve desert	16 mg/kg	Wang *et* al., 2007;
Water	0.9 mg/l	MOH (2005)

MPL: Maximum permitted Limit; MRL: Maximum Residual Limit

2.0 Food Additives use as Preservatives

Food additives are substances which may be synthetics or natural substances as shown in Table 2. They are added to foodstuffs intentionally, to increase the shelf life of the food product and to enhance or modify its properties, including its appearance, flavour or structure, provided it does not reduce the nutritional value. Additives can be of natural or synthetic origin, usually without appreciable nutritional value, they are added to food in small amounts during the manufacture processes or are added during packaging or storage (Silva and Lidon, 2016). There are specific regulatory laws (European Union law) that govern the use, permissibility level or dosage of these additives. The regulations give consideration to the types of food these specific preservatives may be applied, the maximum useable quantity and the chemical characterization and purity standard requirement (Lück and Jager, 1997; EFSA. 2017).

According to Groten *et al.* (2000) and EFSA (2017), preservatives are food additives that protect food against the destructive action of microorganisms such as fungi and bacteria thereby extend the shelf life of food products. Among these preservatives which are commonly used in food preservation are orthophenylphenol, E231 E232, E239 and sodium salt of the orthophenylphenol. Some of these additives are combined with formaldehyde and are said to be active inhibitors of fungal food spoilage, especially when treated with citrus fruit surface (Silva and Lidon, 2016; Groten *et al.* 2000; Galiulova and Dolganova, 2019).

Food additives, as preservative can be combined to increase their potency. For example, citrol (R) is the combination of citric E330 acid and sorbic acid E200, which has synergistic action against microorganisms. In the same vein, E900 (PDMS) Polydimethylsiloxane contains formaldehyde and polymeric organosilicon and is found in variety of foods, including cooking oil, vinegar, chewing gum and chocolate (Chen *et al.*, 2013). Hence, the mode of action and possibly the nature and site of action of each component of these chemical preservative may be different. Three basic concept of joint action or joint interaction, combinations of chemical have been identified (Groten *et al*., 2000). The first concept is called simple similar action; which is also known as simple joint action. The second concept is called simple dissimilar action also known as simple independent action or independent joint action. The third concept interaction describes the combined effect between two chemicals resulting in a stronger effect which promote potential preservative strength of individual chemical or weaker antagonistic inhibition in their combined reactions (Groten *et al*., 2000).

Table 2: Examples of preservatives and their regulatory requirements.

Name	Natural occurrence	Synthetic	Permissible level	Regulatory status in food application
Formaldehyde	√	√	Relative to food	Regulated
Sodium Sulphite	√	√	,,	Regulated
Potassium sulphite	√	√	,,	GMP
Benzoate	√	√	,,	Regulated
Sorbates	√	√	,,	Regulated
Sodium chloride	√	√	,,	GMP/Regulated
Chitosan	√	-	,,	Regulated
Ethanol	√	√	,,	GMP.
Nitrites	√	√	100-200 ppm (meat curing)	Regulated
Potassium nitrate	√	√	200-500 ppm (meat curing)	GMP
Sodium nitrate			Relative	Regulated
Parabens	√	√	,,	Regulate
BHT	√	√	,,	Regulated

GMP- Good Manufacturing Practice, BHT- Butylated Hydroxytoluene

Source: EFSA, 2017; Groten *et al.*, 2000; Wahed *et al*., 2016

Majority of preservatives used recently are synthetics rather than natural. Several of them may be toxic especially when used in quantity beyond the permissible level (Anand and Sati, 2013). Researchers have reported that artificial preservatives such as formaldehyde, nitrites, benzoates, sulfites, sorbates, parabens, BHT, BHA and several others can cause serious health hazards such as hypersensitivity, allergy, asthma, hyperactivity, neurological damage and cancer (Anand and Sati, 2013). However, there are exceptional applications, for example formaldehyde 21CFR173.340 is a defoaming agent, it may be used provided it is a component of defoaming agents, limited to use in processing beet sugar and yeast, and must be subjected to specific limitation impose. Formaldehyde 21CFR173.340 may not be added in an amount not in excess of the reasonably required to inhibit foaming (Blekas *et al.*, 2016; Siva and Lidon 2016).

3.0 Formaldehyde Natural Sources

Formaldehyde is naturally found in foods, either food from a plant sources or of animal origins. The plant sources of formaldehyde includes pear, apple, and green onion while the animal sources are meats, fishes (e.g., Bombay-duck, cod fish), crustaceans and dried mushroom as depicted in Table 3 and Figure 2. It can be present naturally in food up to the levels of 300 to 400 mg/kg (Jung *et al.*, 2021). Some synthetic and natural formaldehyde sources are known and are produced from biogenic emissions (Barokah *et al.*, 2020; Rocco *et al.*, 2020; Mohd Hanif *et al.*, 2021). During the physiological activities of some plants, formaldehyde is released into the atmosphere (Talaiekhozani *et al.*, 2013). A study revealed that formaldehyde is produced by coniferous trees (Müller *et al.*, 2006) and degradation of isoprene in a eucalyptus forest can also lead to the formation of formaldehyde (Trapp *et al*., 2001 and Talaiekhozani *et al*., 2013). Formaldehyde was discovered within a remote forest (Mermet *et al.*, 2020), and a report about formaldehyde emission revealed that it can be produced by free sesame protein (Xiaobo *et. al.*, 2021). Although some researchers believe that formaldehyde can be produced by bio-reaction of OH and NO, some others believe that formaldehyde can be produced by methanol oxidation (Talaiekhozani *et al.*, 2013). Other scientists proposed some possible mechanisms for formaldehyde production by plants like reactions of oxidative demethylation, dissociation of 5, 10-methylene tetrahydrofolate or decarboxylation of glyoxylate (Eisenhut *et. al*., 2019). Although a number of studies were conducted.

Table 3: Natural occurring formaldehyde food sources and their level (mg/kg).

Fruits/Veg.:	**Level**	**Meat:**	**Level**	**Dairy:**	**Level**	**Sea-foods:**	**Level**
Apple :	6.3- 22.3	Beef:	4.6	Goat's Milk:	1	Cod :	4.6 - 34
Apricot:	9.5	Pig:	5.8-20	Cow' Milk:	<3.3	Strimp:	1-2.4
Banana:	16.3	Sheep:	8	Cheese:	< 3.3	Squid:	1.8
Beetroot:	35	Poultry:	2.5 – 5.7			Fish ball:	6.8
Onion (bulb):	11.0	Liver: Paste	11.9			Crustacean:	1-98
Onion (green):	13.3 – 26.3	Process: meat	< 20.7			Duck:	< 140
Carrot:	6.7 – 10						
Cauliflower:	26.9						
Cucumber:	2.3 – 3.7						
Grape:	22.4						
Kohlrabi:	31						
Pear:	38.7 – 60						
Plum:	11.2						
Potato:	19.5						
Spinach:	3.3 – 7.3						
Tomato:	5.7 –13.3						
Water-melon:	9.2						
White-mushroom:	3.7 – 4.4						
Radish-mushroom:	6 - 500						

Source: WHO, 2009; Wahed *et al*., 2016.

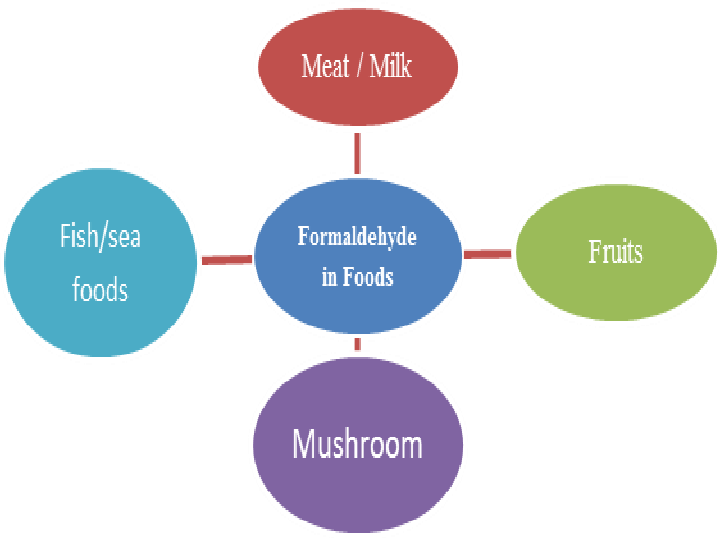

Figure 2: Some natural sources of formaldehyde.

Validation, Investigation about the natural sources of formaldehyde, unfortunately, exact mechanisms of formaldehyde production within plants remains unclear. Marine environments are another natural formaldehyde source (Nuccio *et. al*., 1995; Andersson *et. al*., 2017).

3.1. Formaldehyde from pollution sources

The emissions of formaldehyde from building materials have long been recognized as a significant source of the elevated concentrations of formaldehyde frequently measured in the indoor air. Pressed wood products (i.e., particleboard, MDF and hardwood plywood) are now considered the major sources of residential formaldehyde contamination (Panagopoulos 2011). Pressed wood products are bonded with urea-formaldehyde (UF) resin; it is this adhesive portion that is responsible for the emission of formaldehyde. Due to the improved living standard, people pay more attention to indoor constructions and decorations now, including food factory. This leads to a very serious problem of indoor air pollution, especially organic pollution. Volatile Organic Compounds (VOCs) are the main cause of the detrimental quality of indoor air (Han *et. al.*, 2012).

Over 500 types of VOCs have been detected including formaldehyde. Many researchers only focus on measuring certain types of VOCs. However, the total quality concentrations of volatile organic compounds (TVOC) in indoor air are better index for evaluating indoor air quality (Panagopoulos 2011; SuÃ¡rez-CÃ¡ceres *et al.*, 2020). Formaldehyde is a typical pollutant of VOCs and also the most commonly known indoor air pollutant (Salthammer *et al.*, 2010). Many studies have been compiled to measure TVOC and formaldehyde concentrations (Sakai *et. al.*, 2004). Based on the production mechanism of pollutants, sources of VOCs pollution can be divided into volatile sources (Guo *et. al.,* 2013; Liu *et al.*, 2014), combustion sources and composite sources (Panagopoulos 2011).

Along with more and more proceeding of regular monitoring and identification of pollutant sources, many researchers turned their focus from monitoring to studying the regulatory laws of TVOC and Formaldehyde. They also concluded that the concentration of TVOC and Formaldehyde and the features and usage of pollutant sources are highly relevant (Gilbert *et al.*, 2008). Seasons, temperature, humidity and other environmental factors can affect the concentration of TVOC and formaldehyde too. Huang *et al*. (2015) and Chi *et al*. (2016), discovered that the concentration of some VOCs in indoor air was according to the air exchange rate and are negatively correlated. Later, other scholars confirmed this theory through experiments (Jia *et al.*, 2008).

3.2 Formaldehyde Resin from textile Sources

Formaldehyde resins and relersers are used to enhance the performance of textiles (Lacasse *et. al.*, 2004). A few studies dealing with the release of formaldehyde from textiles are available. Therefore formaldehyde emissions from textiles were investigated by Aldag *et al.* (2017). Steady-state concentrations, surface-related emission rates and mass-related emission rates from formaldehyde were found to be low (Pereira *et al.*, 2016; Salthammer 2019).

3.3 Presence of Formaldehyde in Food as a Preservative

Although formaldehyde is a substance that is naturally produced by every living organism, it can be found in a wide varieties of fruits, vegetables, meats, fish, coffee and alcoholic beverages naturally. Also, it is produced in the human body as a part of normal functions in order to build the basic materials needed for essential life processes (CSF, 2021). The available range of formaldehyde present in many animal and plant species as a product of their normal metabolism varies. It can be found naturally in different proportions in fruits, vegetables, meats, marine fish and crustaceans with levels up to 300 to 400 mg/kg (Murira *et al*., 2020).

Formalin, an aqueous solution of formaldehyde (37–40 wt %), is a colorless liquid which is used as a biological preservative (Nowshad *et al*., 2018). Formaldehyde can be used as a preservative, reducing agent, fumigant, or sterilizing agent in various foods (Jung *et al*., 2021). Recently, it has been reported that formalin is widely used in different tropical countries as an artificial preservative for fruits, vegetables and fishes. There are direct and indirect health hazards associated with formaldehyde and formalin consumptions if not properly applied. However, it is permitted and approved as a food additive (under regulation) (EC. 2022; USAPA. 2010; EFSA. 2014a) meaning it is used in certain materials that have contact with food.

Formaldehyde is used as a food preservative illegally in some cases since it can prolong the shelf life of food by protecting against deterioration caused by microorganisms. Some dishonest traders are using formalin widely in the preservation of food items, like fish, tofu, noodles, vermicelli, milk, meat, salted dried fish and also fruits or vegetables. It is also used to increase the freshness and attractiveness of foods. Recently, it has been reported that formalin is widely used in different tropical countries as an artificial preservative for fruits, vegetables and fish (Nowshad *et al.*, 2018, Islam *et al*., 2017). The Centre for Food Safety (CFS) collected some Bombay duck and needlefish samples for testing. Results found that Bombay-duck samples contained formaldehyde at levels compatible with natural occurrence. There is no evidence on the use of formaldehyde in the Bombay-duck samples. However, in the absence of dimethylamine, formaldehyde was detected (170-570 ppm) in some noodlefish. It was believed that formaldehyde has been added as a preservative after the noodlefish were caught, or during transportation or storage (Nowshad *et al.*, 2018, Islam *et al*., 2017).

4.0 Formaldehyde as Fungicide/anti-parasitic Agent in Seafoods

In cultured fish, formalin is used as a controller of external parasites while in hatcheries, it is used as a fungal inhibitor, especially to control aquatic fungi (Saprolegniaceae). Formalin is an approved aquaculture drug as per USFDA for the control of parasites and fungi in marine fish farming as depicted in Table 4. A routine treatment concentration of formalin ranging from 15-250 mg/l for control of protozoan and nematodes on fish and shrimp and up to 2000 mg/l is used for fungal control on fish eggs, due to its carcinogenic effect, its usage is not permitted for aquaculture in Australia, Europe and Japan (Laly *et al*., 2018). According to Chrissy (2021), Food and Drug Administration (FDA) has also approved the use of liquid formalin in the fishing industry. It is used as an anti-parasitic water treatment for certain types, including salmon and catfish. It is also used for treatment on fungal on fish eggs.

Antora *et al.* (2018) reported the effect of formaldehyde produced from trimethylamine oxide (TMAO) in frozen foods; it reacts with protein during storage and causes protein denaturation and muscle toughness. Also, seafoods, crustaceans and fish proteins undergo biochemical and rheological changes due to high storage temperatures and prolonged storage time.

Table 4: Formaldehyde as preservative agent.

Type	Food and food materials	References
1 Fungicide	Frozen fish, crustaceans, sugar, citrus fruits.	Antora *et al.*2018; Silva and Lidon, 2016
2 Algicide, anti-parasitic	Fish pond water, Hatchery water.	Chrissy, 2021
3 Antibacterial	Milk, fruits, modify starch, seed oil, fruits.	Hossain *et al*., 2016; Nowshad *et al*., 2018; Mabood *et al*., 2017
4 Antifoaming	Oil, fat.	Roxana–Gabriela, 2019
5 Sterilizer	Packaging material.	Laly *et al*., 2018; Jung *et al*., 2021
6 Bleaching	Dry foods vermicelli, tripe and chicken paws.	Wang *et al*., 2007

5.0 Formaldehyde as Preservative in Fruits

The addition of formalin to perishable foods to increase their shelf life is a common feature these days. Fruits are perishable foods, whose shelf life are few days from harvesting; as a result, the fruit traders used formalin to increase the shelf life of the products (Sadia *et al*., 2020). Recently, it has been reported that formalin is widely used in different tropical countries as an artificial preservative for fruits and vegetables. (Nowshad *et al*., 2018).

6.0 Application of Formaldehyde in Milk Products

Adulteration of milk is a malpractice in which food vendors either incorporate cheap substances or subtract valuable components from milk to increase its volume and invariably increase profit margin (Mabood *et al*., 2017). Documented excessively used adulterants include variants of formaldehyde, diluents (water and ice), thickening agents (starch, glucose, urea, flour, salt and chlorine etc.), preservatives (sodium carbonate, sodium bicarbonate and formalin etc.), reconstituting agents (seed oils, cane sugar and animal fats and milk powder), cosmetic agents (detergent/soap and bleaching powder etc.), melamine and others (Mabood *et al.*, 2017). Formaldehyde has repeatedly been used unscrupulously in different foods, especially in milk products among other preservatives (Hossain *et al*., 2016). Formalin is used as an antiseptic, disinfectant and preservative. It is used as an adulterant in milk to increase the shelf life for long-distance transportation of milk without refrigeration, saving the electricity costs for the supplier (Mabood *et al.*, 2017). Despite food legislation, adulteration remains uncontrolled and it is obvious that potentially injurious substances like formalin are being added to milk (Mabood *et al*., 2017).

7.0 Regulations and Health Implications of Formaldehyde as a Food Preservative

Formaldehyde is an economically important chemical, and there is need for proper regulations to prevent excess use beyond permissible limit. It is highly flammable, pungent, colourless, irritating and poisonous when inhale in gaseous form or taken above permitted limit (Tang *et al.*, 2009; Nowshad *et al.*, 2018). Formaldehyde is used as a preservative, antibacterial, bleaching agent, disinfectant, bacteriostatic agent and infections inhibitor in food processing (WHO, 2002; Wang *et al*, 2007; Wilbur *et al.*, 1999). In most cases, formaldehyde is implicated in occupational and environmental exposures; the toxicity is attested to when inhaled, this may lead to respiratory symptoms and irritations of the eye, nose and throat, thus it becomes public health concern (Kim *et al.*, 2011; Zhang *et al.*, 2008; Laly *et al.*, 2018). However major cause of hazards is inhalation of the gas or vapor form of formaldehyde in to the long. The uptake of exogenous formaldehyde into the human body is accomplished via ingestions, inhalations or dermal exposures. Upon absorption, formaldehyde is rapidly converted to formic acid by the action of formaldehyde dehydrogenase and other enzymes, using nicotinamide adenine dinucleotide (NAD) and reduced glutathione to yield the intermediate soformylglutathione, which is subsequently converted to formic acid which is easily eliminate (Laly *et al.*, 2018). However, overdose may be detrimental; hence compliance to permissible level is necessary.

Formaldehyde is used as a food preservative in the food industries in some foods such as fish, dry fish and certain oils and fats because of its nature to harden proteins and prevents food materials from decomposition (Nuriye, 2020; Norliana *et al.*, 2009). Likewise, formaldehyde is used as an antibacterial agent in food industries because of its ability to prevent spoilage from microbial contaminations (Norliana *et al.*, 2009). Occasionally, formaldehyde is added inappropriately during food processing to achieve its bleaching effects on food products such as vermicelli, dry foods, tripe and chicken paws (Wang *et al*., 2007).

Today, global public health is of importance to the United Nations in achieving Sustainable Development Goal 3 (good health and well-being). This has increased the interest of individuals to be more aware of their food intake especially processed foods from unknown sources, that required the use of food preservatives (Wahed *et al.*, 2016). For instance, the consumption of seafood dipped in formaldehyde solution is a great hazard to the health of consumers if the level is beyond permitted level (Zhang *et al*, 2009). The use of formaldehyde as a food preservative is prohibited in some countries: Australia, Hong Kong, Japan and some countries in Europe (Norliana et al., 2009; Mamun et al., 2014; Islam et al., 2017; Amit et al., 2017; Nowshad *et al*., 2018; Laly *et al.*, 2018). The prolonged inhalation of formaldehyde is associated with eye, nose and throat irritation and respiratory symptoms (Zhang *et al*, 2008; Noisel et al, 2007). The consumption of formaldehyde is associated with vomiting of blood, diarrhoea with bloody stool, blood in urine, acidosis, and damage to lungs, liver, kidney and gastro-intestinal tract which may result in cancer (Wilbur, 1999; Alam, 2014; Mamun et al., 2014 Islam et al, 2016; Abdu et al, 2014; WHO, 2001). There is allergic reactions attributed to the use of formaldehyde in household and personal care clothing and textiles and banknote paper (WHO, 2002; Naya and Nakahashi, 2005; Donovan and Skotnicki-Grant, 2007). Likewise, formaldehyde was classified as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC) based on adequate epidemiological evidences which reveals that formaldehyde causes nasopharyngeal cancer in humans (Alam, 2014; Bosetti *et al*, 2008; Duhayon *et al*, 2008).

Although, the use of chemicals to treat food products helps control food spoilage, chemicals such as formaldehyde are associated with negative adverse effects on human beings.

Consumption of formalin regularly can be injurious to the nervous system, kidney and liver, and may cause asthma, pulmonary damage and cancer (Islam *et al*., 2017).

7.1 Food Regulation requirement for formaldehyde applications

Food regulation is a code of conduct adopted by sovereign countries to address or save-guide health, safety and quality goals. Food regulation have international implications on trade and movement of goods, it has much impact on international food business (Aruoma *et al.*, 2006). Food regulation is aimed at protecting the consumer's health, to increase economic viability, harmonizing well-being and engendering fair trade on foods within and between nations (Aruoma, 2006). Agriculture and food trade is growing rapidly with the increasing world population. Hence, high-value products such as meats, fruits and vegetables are in higher demand though perishable; with short shelf life. The safety and quality standard of such food product must be maintained to save-guide food poisoning through contamination. Therefore, technical standard and regulations are required. Acceptable standard and quality index for agriculture and food are evolving worldwide under various focuses. The framework which national rules are embedded, including the enforcement is different from one country to another. There are local and international food regulations, Table 5 and Table 6 (Aruoma *et al.*, 2006; kim *et al.*, 2011; Silva and Lidon 2016; Joslin *et al.*, 2022).

Food additives, including formaldehyde, use in European countries is harmonized by regulations example of such is (EC) No1333/2008 of 16 December 2008 (Blekas 2016; USAFDA. 2022). These regulations concern food additives permitted for use in foods. There are regulations and guidelines regarding formaldehyde exposures (Table 5). The European Union has adopted a directive that imposes concentration limits for formaldehyde and related additives, which are contain in cosmetics, air, water and occupational environments (Kim *et al.*, 2011). Occupational and environmental exposure to formaldehyde has been known to be a public health concern and must be treated so globally (Kim *et al.*, 2011).

There are regulations and guidelines regarding formaldehyde exposure and applications in some countries, Table 5 and Table 6.

Table 5: Regulation, Advisories, and Guidelines Applicable to Formaldehyde.

Countries/Agency	Concentration(ppm)	Type	Ref
Ausralia	1; 2	TWA[a] ; STEL[b]	ACGIH, 2003
Belgium	2	Ceiling[c]	,,
Brazil	1.6	Ceiling	,,
China	0.5	Ceiling	,,
Canada	2	Ceiling	,,
Denmark	0.3	STEL	Kim *et al*., 2011
Finland	0.3	TWA	,,
France	0.5	TWA	,,
Germany	0.3;0.6	TWA; Ceiling	,,
Hong Kong	0.3	Ceiling	,,
Ireland	2	STEL	,,
Japan	0.5	TWA	,,
Malaysia	0.3	Ceiling	,,
Mexico	2	Ceiling	,,
Netherland	1	Ceiling	,,
New Zealand	1	Ceiling	,,
Norway	1	Ceiling; (Executive 2002)	HSE 2002; Lu et al., 2010
Poland	1	Ceiling	Kim *et al*., 2011
South Africa	2	STEL	,,
South Korea	2	STEL	,,
Spain	0.33	STEL	,,
Switzerland	0.6	STEL	,,
United Kingdom	2	STEL	,,
United State	2	STEL	,,

[a]TWA: Time-weighted average; [b]STEL: Short-term exposure limit;

[c]Ceiling: the value that should never be exceeded during any length of time;

[d]TLV: threshold limit value.

America Conference of Government Industrial Hygienists stipulated 0.3ppm, as threshold limit value, Occupational safety and health administration stipulated 0.75ppm as time-weighted average and Environmental protection agency stipulated 2ppm as Short-term exposure limit and 0.7ppm as threshold limit value. The challenges of food standard regulation of formaldehyde like other regulated food additives goes further to how to achieve appropriate balance within countries, between reliance on domestically determined and internationally agreed-on product specifications. Secondly, how to enhance confidence of the consumers and the cooperation of the producers in implementing regulations and strict adherence to stipulated standards and regulations. More so, many of the standard and regulations are influenced by socio-political and religious values (Joslin *et al*., 2022; Wahed *et al*., 2016).

Table 6: Some Regulatory Citation of Formaldehyde and Food Additves.

Citation number/CFR	Food Category	Permitted Functionality	Use limitation
21CFR173.340. Secondary direct food additives, permitted in food for human consumption as defoaming agent.	Defoaming agent	Surface active agent	As preservative, processing beet sugar and yeast, limited to GMP
21CFR175.105 Indirect food additives; adhesives	Adhesive, as component of packaging materials	Indirect food contact, Coating component	Dried food; not exceed GMP
21CFR178.3120 Indirect food additives, Adjuvant, production aid, sanitizer. Animal glue	Animal glue	For use as a preservative	Limited to GMP
21CFR573.460	Animal food	Formulation aid	No restriction

Sources: USA Food and Drug Administration 2022; Blekas, 2016

CFR: Code of Federal Regulation, GMP: Good Manufacturing Practices

8.0 Conclusion and way forward on the application of formaldehyde as preservatives in food and food packaging

Considering the negative impacts of formaldehyde in foods, those countries that allow the use of this preservative in food should act fast to enforce the required regulations of the products. Alternative safe food additives should be used in order to safeguard the health of citizens. In any case, if it is used in the food products as preservatives, it should be indicated on the labels and flagged with color code to serve as a caution (Kim *et al*., 2011; Pereira *et al*., 2016).

Although formaldehyde is a natural metabolic product of the human body, high-dose exposure to the synthetic forms the additive increases the risk of acute poisoning, while prolonged exposures can lead to chronic toxicity and even cancer. Today, food and color additives, including preservatives such as formaldehyde, are more strictly studied, regulated and monitored than at any other time in history in developed countries, and FDA has the primary legal responsibility for determining their safe use in the United State. In most developing countries, regulations on the use of formaldehyde has not been prioritized. Therefore utmost attention should be given to the regulations concerning inclusion of formaldehyde in imported and frozen foods especially chicken and fish imported to most developing countries especially Africa countries. The safety of food additives must be monitored regularly to make sure the amount and type of additives follow the guidelines in the Food and Drug regulations. The health implications of indiscriminate use of formaldehyde must be well communicated to the food processors and the retailers to safe guard the health of consumers. The regulatory laws that check the use, permissibility and level or dosage of this additive must be enforced when necessary to prevent the spread of detrimental health challenges to unsuspecting consumers (Goon *et al.*, 2014; Park *et al.*, 2021; USAFDA, 2022).

The assessment of formaldehyde in displayed processed and stored foods must be done regularly and any food handlers culpable of unscrupulous use of formaldehyde should be prosecuted by the authorized agencies. Consumers should be educated to patronize safe and reliable food brand, choose fresh frozen foods, and avoid those with an unusual smells. Thorough washing and cooking of suspected food products will reduce the load of formaldehyde as it is a water-soluble chemical and could dissipate upon heating. However, it is necessary to add that the effect of formaldehyde are more concentration-dependent rather than exposure duration (Arts *et al.*, 2008; Goon *et al.*, 2014; Laly *et al.*, 2018) and the toxicity of formaldehyde is route-dependent and health effects depend on portals-of-entry (Wolkoff and Nielsen, 2010; Laly *et al.*, 2018; Park *et al.*, 2021).

Authors Contributions

AO. Adeoye: formal analysis, Conceptualization, Editing. GM. Babarinde: Investigation, Methodology, Validation. GM. Adegbola: Investigation, Validation, J. Oyedokun: Writing of the Manuscript and Investigation. OW. Alawode: Writing manuscript, Editing. Olalere DF.

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