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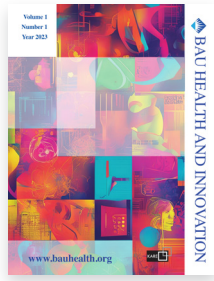

Review

Development of Taste Sensation in Infants and Affecting Factors

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Abstract

Infants' taste and olfactory chemosensory systems develop early in life and are open to learning. Early feeding experiences form an important part of learning to enjoy and accept the tastes and flavors of foods specific to the infant's feeding environment and culture. The process of infants becoming accustomed to tastes begins with the intake of amniotic fluid in the womb and is a journey that continues throughout the breastfeeding period. The transition to complementary foods further increases infants' exposure to flavors by introducing new foods into their diet. Although genetic factors can influence individual differences, repeated exposure to foods can shape innate taste preferences. Therefore, it is important to provide diverse food from an early age. This review underlines the important role of the sense of taste in infant food consumption.

Keywords: Complementary feeding, eating behavior, infants, taste preferences.

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The nutrition of the infant from the mother's pregnancy period through the first 2 years significantly impacts their health status in later stages and throughout life. The World Health Organization (WHO) defines complementary feeding as "a transition period from exclusive breastfeeding to the introduction of other foods and liquids, that is, family foods" when breast milk alone is insufficient to meet the infant's needs.[1] With complementary feeding, infants transition from a milk-based diet to one that includes various solid foods. Feeding practices and taste preferences emerge during this early period and are carried over from infancy to childhood and adulthood. WHO recommends exclusive breastfeeding for the first 6 months and the introduction of appropriate complementary foods starting from 6 months of age, continuing alongside breast milk until at least 2 years of age.[2] A timely, adequate, and balanced introduction of complementary foods is one of the key strategies directly addressing infant malnutrition. These early life experiences are crucial in terms of the infant's nutritional status and outcomes. The acceptance of certain foods may be more challenging than others, and these differential preferences are based on biological foundations: Sweetness is inherently liked from birth, whereas bitterness is initially disliked, but this can change with experience and repeated exposure. It is also recognized that the programming of food preferences, eating habits, and health outcomes in later life stages is important.[3–5]

Pregnancy and Amniotic Fluid

Throughout life, flavor, particularly taste and smell, is a product of various sensory systems and serves as a potent determinant of feeding behavior. The taste and smell

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chemosensory systems in infants develop early in life and are receptive to learning. These sensory experiences can shape food preferences.[6] A baby's first encounter with flavors begins in the mother's womb. Limited yet consistent evidence suggests that flavors from foods and beverages consumed during pregnancy can transfer to the amniotic fluid and impart flavor, enhancing the acceptance of these tastes through fetal exposure during infancy and potentially into childhood.[7] The baby's perception of taste develops through the transfer of flavors from the mother's diet to the fetus's amniotic fluid. This process is followed by the lactation period. The taste of breast milk varies according to the mother's diet. Due to a different enzymatic process and substrate model, the lactation phase can lead to changes in flavor composition. Thus, breastfed babies become accustomed to different flavors through colostrum and mature milk.[8] Furthermore, breast milk is an ideal nutrition source for growth and development in the early years of life, providing various bioactive components beneficial for infant health.[9] Existing studies suggest that the flavor of breast milk may change depending on storage temperature and duration, but it remains unclear whether infants perceive these changes.[10]

It has been determined that flavor compounds and volatile components pass into breast milk. In studies conducted by Spahn et al.[6] to determine the effect of maternal diet on the odor profile of milk and newborn sucking behavior, ethanol, garlic, carrot, and tobacco intake were shown to alter the taste of milk. In addition, in other studies, it has been observed that cumin, anethole, menthol, vanillin, caffeine, theobromine, and paraxanthine also change the taste of breast milk.[11] Although not all consumed flavor compounds pass into breast milk, it is clear that a large proportion do. Moreover, biotransformation of flavor compounds can form new molecular structures that can pass into milk in a similar way to digested compounds.[12]

Randomized controlled trials have provided examples of how maternal consumption of carrot juice during lactation results in infants being more readily accepting of carrot-flavored food during weaning compared to infants of mothers who consumed water.[13,14] These findings demonstrate that breastfeeding facilitates the acceptance of new flavors. In addition, according to the results of other studies, breastfed infants exhibit a faster acceptance of new foods and flavors compared to formula-fed infants, find vegetable varieties easier to accept, and experience less difficulty transitioning to new foods as they grow.[15] Thus, it is evident that beyond learning food preferences and specific tastes, infants nourished with breast milk play a significant role in facilitating the acceptance of foods. Mothers who consume diets rich in healthy foods may facilitate the acceptance of these flavors in their infants through exposure to these flavors through amniotic fluid and breast milk. Conversely, infants fed formula may struggle with accepting flavors that are not present in the formula due to adaptation to a single flavor profile.[6] Variations in taste from mother to mother and from feeding to feeding suggest that breastfeeding, unlike formula feeding, has the potential to provide infants with a rich source of sensory diversity. The more varied the mother's diet during breastfeeding, the richer the taste of her milk, which may explain why breastfed children are less selective and more eager to try new foods as they grow.[14] Another benefit of breastfeeding is that the properties of breast milk compounds are associated with appetite control mechanisms during infancy. Unlike formula, the composition of breast milk fat content varies during each lactation period. Therefore, it has been suggested that breastfed infants can more easily control their food intake and thus their appetite in response to changes in macronutrient content and appetite-related hormones in breast milk.[15] The duration of breastfeeding also influences the development of infants' taste sensations. The longer the duration of breastfeeding, the easier it is for a 6-month-old infant to accept the umami taste. In summary, longer breastfeeding duration is associated with increased intake of fruits and vegetables.[16] Breastfeeding allows infants to better control hunger and satiety signals compared to bottle feeding, enabling infants to self-regulate their energy intake.[17] Breastfeeding may also promote a slower eating pace. Bottle feeding in formula-fed infants can increase feeding speed. Eating slowly may help promote the development of obesity-protective eating behaviors in infants. In conclusion, it is assumed that breastfeeding supports the development of food preferences, eating pace, and appetite control mechanisms through various pathways.[18]

Breastfeeding and Formula Feeding

Breast milk contains vital compounds that provide specific tastes, such as lactose for sweetness, glutamate for umami or salty taste, sodium for salty taste, urea for bitter taste, and long-chain fatty acids for oily taste.[9] Mastorakou and colleagues found in their study with 22 mothers that sweetness was the dominant primary taste in breast milk. They reported that the estimated average sweetness intensity of human milk is equivalent to a 1.53% sucrose/water solution.[11] The development of taste perception varies between breastfed and formula-fed infants. The introduction of formula milk and other complementary foods represents a crucial period during which infants can alter their taste preferences and

also contributes to obesity prevention.[19] Infants solely fed formula milk cannot benefit from the rich taste profile of their mother's milk: Their taste experiences are weaker because they do not experience the tastes of various foods in their mother's diet. Different varieties and brands of formula milk products may contain different tastes: Milk-based formulas have a low sweetness level and are described as "sour and cereal-like" in taste; soy-based formulas have sweet, sour, and bitter tastes; hydrolyzed formulas are described as extremely sour and bitter compared to those for adults, hence their tastes are unpleasant. Formula-fed infants learn to prefer the tastes associated with the formula milk they are fed. This affects their taste preferences in later years. The composition of protein, fat, and carbohydrates in infant formulas may vary, which can also influence growth, health outcomes, and taste preferences.[8,9]

Infants Taste Sensation and Food Choice

Sensory preference development initiates in utero; babies' taste and smell systems emerge in the first 3 months, reaching functional maturity by the end of pregnancy. Taste is defined solely as the sensation arising from taste receptors, but the term flavor is more inclusive, encompassing the complex of sensory cues including smell, taste, and touch systems. Flavor preference is one of the factors that influence children's food intake and eating habits. Humans perceive six primary tastes.[1] Sweetness is perceived mainly by sugar derivatives like fructose or lactose, but other substances like amino acids found in fruit juices can also activate the sweet taste receptors.[20,21] Sourness is mostly perceived through acidic solutions like lemon juice or organic acids, caused by hydrogen ions.[22] Saltiness is mainly perceived with foods containing table salt, chemically composed of sodium and chloride crystals, though the sensation of saltiness can also stem from other mineral salts such as potassium or magnesium.[2] Bitterness is perceived through various components found in brassicaceous vegetables (e.g., broccoli and cabbage). Humans have 25 bitter taste receptors, with TAS2R38 being the most utilized in bitter taste perception. Response to bitter taste sensitivity can vary from individual to individual based on genetic variations in this receptor.[3] The umami taste is caused by glutamic or aspartic acids, providing a flavor similar to that of meat broth, also found in some plants such as ripe tomatoes or asparagus. Oleogustus, described as the fatty flavor, is identified as the sixth primary taste. Stimulants that impart the taste of fat in the diet are unsaturated fatty acids. Specifically, medium and long-chain fatty acids provide a distinct sensation of taste compared to other basic tastes (sweet, bitter, sour, and salty).[4]

Taste Perception: Sweet

Infants are born with a preference for sweet taste, which explains their tendency to prefer foods high in sugar or salt as potential sources of energy while avoiding bitter tastes. Sweetness enhances the palatability of foods and beverages, directing infants toward the intake of such foods. Taste perception can vary among individuals depending on variations in taste receptor genes. Sensitivity to sweet foods and preference for them may be influenced by polymorphisms in the TAS1R taste receptor gene.[17]

Innate taste preferences are adaptable, and the preference for sweet taste allows infants to reach their first source of sustenance, which is typically sweet-tasting breast milk high in lactose. Regarding exposure to sweetness in breast milk, samples of breast milk obtained from 20 lactating volunteers with 7-month-old infants revealed the presence of saccharin, sucralose, and acesulfame potassium. However, it is still unknown whether this content will influence long-term taste preferences.[23]

Experimental research indicates that the rewarding properties of sugar and salt are more pronounced during infancy.[6] In a study, it was found that 25% of infants who were given sugary water as part of their diet preferred sugary water as their first choice at 6 months of age, whereas this preference was not observed in infants fed with breast milk or formula.[24] In a study investigating the effect of exposure to a sweet or sour beverage containing sucrose on sweetness preference and liking for sweet and sour products in children aged 4–7 years (n=65), it was found that exposure to a sweet or sour beverage containing sucrose 14 times did not affect sweetness preference or liking in children aged 4–7 years. However, it was observed that sweetness preference increased from baseline to post-intervention and remained high until the end of follow-up.[25]

Infants can learn preferences for the foods offered to them, so the innate preference for sweet taste can be partially altered by food experiences even in early infancy.[26] Excessive consumption of energy-dense, palatable, and sweet foods poses a risk factor for obesity. Current studies focus on improving children's diet quality with an appropriate complementary feeding plan. A cohort study involving 1041 children suggested that encouraging the preference for nutrient-rich foods over sweet and energy-dense foods in complementary feeding may be associated with higher diet quality during childhood.[27]

Taste Perception: Salty

Sodium is an essential nutrient for the human body. Salt is added to foods to enhance their flavor. Salt addition not only

increases the saltiness but also suppresses bitterness. When bitterness is reduced, the sweet taste of food becomes more prominent, creating a generally favored flavor profile. The measurement of salt taste sensitivity is typically done with salty water, while the assessment of children's hedonic response to salt in foods is often conducted by adding salt to suitable foods such as soup, broth, and crackers. Newborns (1–4 days old) showed indifference to salty taste when given salty water (4.3 g salt/100 mL water), possibly because their salt taste perception system may not be mature enough to detect salty taste until later. Despite being born with a biological need for sodium, the first food a baby encounters is breast milk, which is dominated by a sweet taste and contains sufficient sodium for the baby's development. Observations have shown that when babies perceive the taste of salt, they prefer salty water over plain water. The preference for salty water in babies does not require prior exposure to salty taste, indicating an innate biological response to salt taste. However, this does not imply that adding salt to any baby food will increase its consumption. [3] Postnatal severe sodium deficiency and excessive sodium intake may lead to an increase in preference for salty taste. Sodium deficiency during infancy and childhood is rare outside clinical populations. Severe vomiting and/or diarrhea attacks during infancy can cause electrolyte imbalances. However, in later years, preferences for salty foods tend to increase. Similarly, implementing a diet high in sodium enhances the preference for salty foods. In populations consuming high-sodium diets, it is thought that infants' salt preferences may increase during certain stages of growth due to their biological needs for minerals.[3,28]

Complementary feeding introduces high-sodium foods into infants' diets, such as grains. A longitudinal study conducted in Australia revealed that infants aged 9–18 months experienced a doubling of sodium intake, with bread and rolls contributing the most to total sodium intake.[28] Current studies suggest that infancy may be a potentially sensitive period during which salt taste preferences can be altered. High sodium consumption can lead to the development of high blood pressure in childhood and adulthood. Children may become accustomed to excessive salt intake and expect their foods to have a certain level of salty taste. This result of high salt consumption can potentially lead to the consumption of unhealthy foods during childhood and adulthood.[27]

Taste Perception: Bitter

Infants show reluctance toward bitter and sour tastes, and they reject the intake of bitter taste due to the potential relationship between bitter taste and toxicity. Considering that poisons often have a bitter taste and solid foods may contain a sour taste, these taste preferences may explain why infants are hesitant to consume foods that could harm them. All other taste preferences, however, are learned through exposure.[29,30] For example, bitter tastes like some vegetables are often rejected when first experienced but can become acceptable with increased exposure.[31,32]

Taste preferences are also related to previous experiences, developmental stages, and genes that affect taste perception. The taste receptor TAS2R38, responsible for bitter taste perception, and genotypes such as 6n-propylthiouracil (PROP) and phenylthiocarbamide influence taste perception ability. Children with PROP genotypes insensitive to PROP may have a higher likelihood of accepting vegetables. Insensitivity to PROP is observed in approximately 30% of Europeans and varies worldwide. PROP sensitivity is associated with perceiving the taste of bitter foods less, consuming fewer vegetables, experiencing more food aversion, and having a higher risk of childhood obesity.[3] Analysis of numerous studies has observed that infants consuming protein hydrolysate formula predominantly perceive bitter taste. It has been found that infants exposed to bitter taste through formula feeding tend to consume more bitter taste later in life. As a result, it is believed that the liking for bitter tastes can be learned.[24]

Maternal diet affects the sensory properties of breast milk. Alkaloids responsible for bitter taste perception can be transferred from the maternal diet to breast milk. A significant relationship has been found between the perceived bitterness of foremilk and the bitterness of the maternal diet consumed before lactation. Based on this finding, increasing vegetable consumption among breastfeeding mothers can be recommended. However, adding extra spicy foods to the diet of breastfeeding mothers is not advised. This is because various bioactive compounds from spicy foods and beverages that need to be restricted during breastfeeding (e.g., caffeine, alcoholic beverages, etc.) can pass into breast milk.[11]

Cultural differences in solid food exposure during the transition to complementary feeding influence culturally determined food preferences in infancy and childhood. In some cultures, infants and children are deliberately exposed to strong flavors. This may explain cultural differences in foods that children find palatable. For example, in Mexico, children are given foods flavored with increasingly spicy peppers. Initially, they may not prefer foods containing unpleasant flavors, but learning to enjoy these foods could be part of the socialization process. Food preferences

and eating behaviors vary depending on complementary feeding practices.[17] Regardless of sensitivity to bitter taste, repeated exposure to taste has been confirmed as a good strategy to increase vegetable acceptance in children.[33]

The Development of Taste Sensation Alongside Complementary Feeding

Due to the rapid continuation of growth and increased mobility of infants, breast milk alone may not suffice to meet the nutritional needs of the baby starting from the 6th month. However, it is essential to continue breastfeeding due to the presence of nutrients, growth factors, antimicrobial agents, and essential unsaturated fatty acids not found in breast milk, complementary foods, or formula milk. Complementary foods are necessary to fill the gap between the baby's total nutritional requirements and the amounts provided by breast milk. Failure to fill this gap may result in slowed or halted growth and development. Therefore, regardless of the feeding method used, complementary feeding is recommended for every infant reaching their 6th month. There are still some debates in the literature regarding the appropriate timing to initiate complementary feeding. According to the general recommendation of the WHO, exclusive breastfeeding should be encouraged for the first 6 months of life, followed by the introduction of complementary foods starting from the 6th month.[2,34] The European Food Safety Authority, in its revised panel, considers that instead of a specific age, there could be an appropriate age range for introducing complementary foods to infants. The appropriate age range depends on the individual's characteristics and development. As long as foods are provided in an age-appropriate texture, suitable for nutrition, prepared with good hygiene practices, and under appropriate conditions, there is no definitive evidence regarding the negative or beneficial health effects of using complementary foods (excluding infants at risk).[35] The European Society for Pediatric Gastroenterology, Hepatology, and Nutrition recommends the introduction of complementary foods, including allergens, between 4 and 6 months of age.[36,37]

According to the WHO recommendation, exclusive breastfeeding is sufficient for the first 6 months, as breast milk meets the nutritional needs for the baby's growth and development. After the 6th month, complementary foods should be introduced alongside breast milk. Complementary foods refer to solids and liquids added to the diet and do not include formula as a complementary food.[35,36] During the first 6 months, breast milk intake can meet the baby's needs for water, energy, protein, calcium, and many other nutrients. Maintaining exclusive breastfeeding until the 6th month is crucial for maximizing the benefits of breast milk, considering its protective effect against infectious diseases. However, for some infants aged 4–6 months, breast milk may not provide sufficient iron and zinc. In such cases, complementary foods need to be introduced.[35] As infants experience rapid growth and development during this period, it is recommended to offer a diverse diet with a variety of tastes and textures. The process of developing taste preferences through trying different foods is highly important.[36] A randomized controlled study suggests that promoting vegetable consumption during infancy is an effective strategy for shaping taste preferences in later years. Therefore, introducing children to vegetables first and offering a variety of vegetables may contribute to the development of healthy eating habits.[38]

Acceptance of Vegetables and Fruits

People instinctively reject bitter foods to avoid common toxic compounds found in plants. This innate aversion to bitter foods has been crucial for human survival. Especially in children, taste often shapes food preferences.[11] Early taste experiences can influence infants' food preferences and choices. The innate rejection of vegetables by babies may stem from their low energy density and/or unpleasant tastes. A study showed that repeated exposure to vegetables not only increases vegetable acceptance in the short term but also up to at least 3 months after exposure. Reinforcing the repeated presentation of rejected foods can modify infants' food choices by parents.[39] Thus, the variety of vegetables given to infants at the beginning of complementary feeding and early exposure to vegetables confirms to increase in the acceptance of new vegetables.[40,41] The timing of taste exposure is also a factor influencing vegetable acceptance. This timing effect suggests that early exposure (within 0.5 months after birth) is stronger and facilitates vegetable acceptance more than late exposure (within 1.5/2.5 months after birth).[14] A longitudinal study conducted over 6 years from birth found that maternal consumption of vegetables and fruits during pregnancy, as well as longer breastfeeding duration, were associated with increased vegetable/fruit consumption in children up to the age of 6.[42] Another study reported an increase in garlic-flavored food intake in children aged 8–9 when a group of mothers consumed garlic during pregnancy. Thus, prenatal exposure to a specific taste has shown a positive relationship with accepting the food later in life.[43]

Early determination of infants' vegetable and fruit preferences is crucial as they learn to eat solid foods. Factors influencing the acceptance of vegetables and fruits at the

beginning of complementary feeding include breastfeeding experience; timing of introduction to complementary feeding; repeated exposure to foods; variety of foods offered since the start of complementary feeding; quality and sensory characteristics of complementary foods; feeding schedule; and responsive feeding by parents.[44] A study investigating the effect of taste on the acceptance of new foods at the onset of complementary feeding found that infants aged 5–7 months reacted more positively to new vegetables when they were salted or contained a salty component. However, this finding should not encourage parents to use salt or salty ingredients, as sodium is not recommended for babies.[45]

For infants to have a healthy start, it is recommended that mothers consume vegetables during the breastfeeding period. While we may define early infancy as a time when infants may be more receptive to learning the flavors of vegetables in breast milk, learning to enjoy foods should continue throughout childhood. However, high consumption of fruits and vegetables is associated with a lower body mass index in childhood and adolescence.[46] The early stages of life represent a sensitive and optimal period for learning new flavors. Effective complementary feeding strategies can create a flavor bridge by mimicking the taste experience in breast milk, thereby enhancing the acceptance of vegetables in complementary feeding.[47]

Conclusion

From the early stages of life, it is known that infants' sensory experiences shape their food and flavor preferences. During this process, infants can discern basic tastes such as sweet, sour, bitter, and umami, while their response to salt taste matures after birth. Innate preferences for sweet and umami tastes, along with the rejection of bitter and sour tastes, reflect fundamental biological reactions in human infants. These preferences encourage the consumption of nutritionally rich foods while preventing the ingestion of toxic plants, reflecting the outcomes of evolutionary selection. The initial flavor experiences begin during the fetal period through exposure to amniotic fluid and continue with breast milk after birth. During breastfeeding, the mother's consumption of healthy and diverse foods supports infants in making a healthy start. In the early period, infants are more receptive to learning the nutrients present in breast milk, but learning to enjoy healthy foods should continue throughout childhood. Transitioning to complementary foods, infants find it easier to accept new and diverse flavors. Initially disliked foods may become more accepted through repeated exposure, expediting the process of familiarization. Nutritional preferences and flavor experiences during infancy also influence dietary choices in later life stages. Therefore, the dietary habits acquired during this period form the basis for lifelong dietary patterns. Providing infants with nutritious and varied foods can instill healthy eating habits. Consequently, a better understanding of the formation of eating habits and flavor preferences during infancy can contribute to the development of healthy eating habits.

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