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What do cloves, cinnamon, nutmeg, and basil have in common? Maybe you recognize each of them as common culinary herbs, which they are, but there is actually a characteristic molecule that is found to some extent in each, referred to as eugenol. Eugenol is an organic molecule consisting of a six carbon ring of alternating double-bonds; two oxygen atoms are singly-bonded to carbons in the ring, one of the oxygen atoms is single-bonded to another carbon with three hydrogen atoms and the other is bonded only to hydrogen; another carbon atom is singly-bonded to a remaining carbon in the ring, which is bonded to two other carbons each of which are also bonded to hydrogen atoms. Whew, that was a lot of words. The best way to understand how the atoms fit together is to see its skeletal formula and a ball and stick model, each of which are in the public domain and can be found on Wikipedia [1], but are shown in the margin for convenience. It is considered a phenylpropene molecule [1], the "phenyl" part of the word meaning that it contains a modified benzene ring (6 carbon atoms with hydrogen normally attached to each) with an allyl group attached (a side group $H_2C{=}CH\text{-}CH_2R$, where R is the rest of the molecule [2]). The terminology given and how all this fits together will be interesting to learn about in organic chemistry. Its molecular formula is $C_{10}H_{12}O_2$.

Cloves, cinnamon, nutmeg, and basil are some of the well known natural (plant) sources of eugenol. It varies in concentration in each type of plant from which it can be extracted as an essential oil, which is said to have the "essence" of the plant that gives it its taste and smell. For instance, the essence of cloves can be generally extracted using an organic solvent such as olive oil which will dissolve some of the eugenol in the plant matter [3]. This would work given the principle of like molecules dissolving like molecules. The smaller the plant can be broken up the better, which increases the surface area of the particles being dissolved. The olive oil will have the essence of cloves, but this is not pure eugenol.

Fig. 1 Pictured are the spices cloves, cinnamon, and nutmeg with a basil plant.

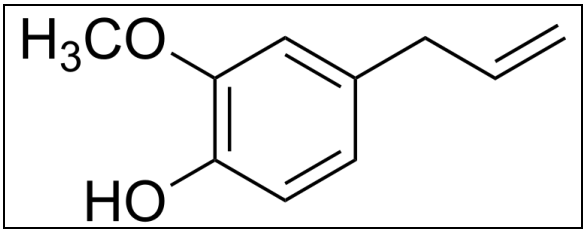

Fig. 2 Skeletal formula of eugenol.

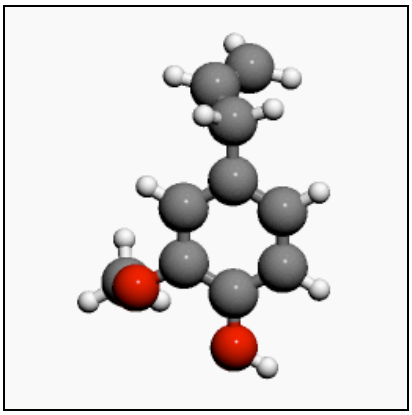

Fig. 3 Ball and stick model of eugenol.

To further refine the plant towards pure eugenol, distillation and selective precipitation processes would need to be employed. If purification was needed, distillation would take the place of the olive oil. Eugenol has a boiling point of 254°C and can be steam distilled from freshly ground clove, which sounds like a fun organic chemistry experiment (there looks to be several example experiments available online) [4].

Cloves' distinctive taste is said to carry the flavor of eugenol [5], which makes sense given the consistently high concentration of eugenol in cloves, which is on the order of 72-89% in the extract [6][7]. The cloves that we eat come from the flower part of an evergreen tree, *Syzygium aromaticum*, native to Southeast Asia [8]. The flower is dried (see figure 5) and then often ground to a powder to be paired with compatible foods, like coupled with apple cider and cinnamon!

The distinctive and familiar flavor of cinnamon is not due to eugenol, which has a very different taste than cloves. This may be due to the part of the plant we eat, which is from the inner bark of a tree (see figure 6), as eugenol is said to be found primarily in the leaves of a cinnamon tree [9]. There is also a lot of variation in the genus *Cinnamomum* that seems to have a large affect on the concentration of eugenol found in its leaves, from trace levels to about 80% in its essential oil [10]. Given the general association that eugenol tastes like cloves, when compared to cinnamon or to even nutmeg and basil which generally contain smaller amounts of eugenol, the vastly different flavors signify that the differences in taste are due to other chemicals present within the parts of the plants we eat. In light of the information we have such as the relatively consistently high concentration of eugenol in cloves, and using taste as a guide, it seems that the most efficient source of eugenol is cloves.

Fig. 4 Clove essential oil in clear glass vial. From Wikipedia article.

Fig. 5 Cloves. From Wikipedia article.

Fig. 6 Cinnamon. From Wikipedia article.

If you've ever tasted cloves, you may find that it has a bitter taste with a slight tongue numbing affect, due to eugenol. This same affect has found its way into anesthetic applications such as for relieving pain in dentistry or even to immobilize organisms during ecological research of marine life. As in most situations where there are benefits, there are also concerns. In dentistry, there have been cases of severe allergic reactions even to the point of death. Even though it is a natural substance, in its purified form it can cause tissue hypersensitivity and should not be applied undiluted [11]. Patients that are concerned about whether or not they are allergic can take a patch test. A major concern in marine life research is that using pure eugenol to immobilize fish underwater can decrease growth and can kill off coral reefs near the study area [12].

Eugenol has shown to be an effective antibacterial agent, such as against *Salmonella typhi*. Results of studies suggest that eugenol can break down a bacterial cell membrane [13]. Its antibacterial properties are being developed in nanoemulsion delivery studies to use eugenol as a food preservative. For example, various oils and surfactants mixed with eugenol were tested against *Staphylococcus aureus* in fruit juices and shown to be effective against microbial spoilage [14].

Nature has also found some applications for eugenol. Like its distinctive taste, it also has a distinctive smell. For example, a Southeast Asian orchid uses eugenol derivatives, among other chemicals, to attract its pollinator, the male fruit fly. The fly in turn metabolizes methyl eugenol into a female-attracting pheromone [15].

Interestingly, these spices containing eugenol were so prized by humans that even regions and treasures were traded for them. It is said that Magellan sent back a ship of cloves from the Spice Islands (Indonesia) which was the most valuable spice in his time. People believed that "clove essence could improve vision, its powders could relieve fevers, and mixed with milk it could enhance intercourse. [16]" To settle the Second Anglo-Dutch War (1665-1667), the Dutch agreed not to press their claims on New Netherland. In return, they were granted an island rich in nutmeg. New Netherland was renamed by the English to New York. So it seems that if it wasn't for a derivative of eugenol (a component of nutmeg), it may be that Americans would speak Dutch and not English [17].

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