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Progress in Sensory Biology: Implications for Vertebrate Pest Control

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ABSTRACT: During the past two decades, remarkable progress has been made in understanding the receptor events for detecting and processing information by the chemical senses (taste, smell and chemical irritation or chemesthesis) of vertebrates. This new information offers expanded opportunities to exploit the chemical senses of vertebrate pests to attract them, repel them, or otherwise modify their behavior in a manner that mitigates their potential to do damage. Here, I describe one example of each of these chemical senses. *Irritants* are attractive candidates for vertebrate repellents since they activate pain receptors, are innately avoided, and may be relatively non-toxic. Identification of specific irritant receptors and receptor cells has heightened interest in understanding sensory processing and species differences in this chemical sense. Molecular-cellular techniques with isolated cell-based systems can be used to screen for efficacy of irritants in previously uninvestigated species. These techniques can be both predictive and cost effective. *Odors*: Animals with certain diseases can be identified by an altered body odor. Next steps will include the identification of diagnostic odorants and a broader understanding of mechanisms of the odor message processing. Development of novel sensor devices using detectors such as DNA fragments, pheromone-binding proteins, and immobilized odor receptors may provide breakthroughs in our ability to detect and monitor disease vectors in the natural environment. *Tastes*: Animal species vary in their sensitivity to taste compounds, presumably as a consequence of ecological selective pressures. For example, cats, obligate carnivores, have no preferences for sweet carbohydrates due to an evolutionary change in a gene responsible for coding for the sweet receptor. Thus, the cat sweet receptor gene has been pseudogenized, presumably as a result of relaxed selection. A better understanding of the molecular biology of taste receptors in a species of interest, be it an endangered animal or a pest such as a pig or deer or coyote, should help in designing novel and effective repellents and attractants.

KEY WORDS: attractants, chemesthesis, chemical senses, disease, odors, repellents, smell, taste

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INTRODUCTION

During the past two decades, remarkable progress has been made in understanding the initial events in detecting and processing information by the chemical senses of vertebrates. In the early 1990s, Buck and Axel (1991) published their Nobel-Prize-winning paper suggesting that volatile odorants are detected by a family of 1,000 or more receptors. This work was followed by the discovery of additional families of receptors in the vomeronasal organ that detect volatile and non-volatile compounds. Thus, the proportion of the genome devoted to detecting odors (in the broad sense of this term) exceeds several percent, a most remarkable genetic investment in a single sense (see review by Touhara 2008).

Discovery of receptors for the sense of taste took almost a decade longer, but beginning in 1999 and continuing rapidly over the next several years, putative receptors were identified for sweet, bitter, and umami taste qualities. Sour and salty receptor identification still remains to be accomplished (see review by Bachmanov and Beauchamp 2007). Finally, for the third major chemical sense, irritation or chemesthesis, a plethora of receptors and receptor mechanisms have recently been identified for such stimuli as capsaicin (the burn of hot peppers), menthol (cooling), and mustard oil (sting) (see review by Simons and Carstens 2008).

This new information offers expanded opportunities to exploit the chemical senses of vertebrate pests to attract them, repel them, or otherwise modify their behavior in a manner that mitigates their potential to do damage. Here, I discuss one example of each of these chemical senses.

My purpose is not to provide insights into how to control vertebrate pests, but instead to illustrate some of the exciting possibilities that warrant further development work.

DISCUSSION

Chemesthesis

Irritants are attractive candidates for vertebrate repellents, since they activate pain receptors and thus are innately avoided, even though they may be relatively non-toxic as is the case for capsaicin. In collaborative work done over the past decade with the USDA National Wildlife Research Center, Monell scientists studied species differences in the activation of isolated trigeminal neurons (Kirifides et al. 2004) sensitive to irritants and demonstrated that birds, unlike mammals, do not respond negatively to capsaicin. More recent work by Jordt and Julius (2002) has shown that the receptor sensitive to capsaicin in mammals is insensitive to it in birds. Presumably, some plants have been selected for an ability to synthesize capsaicin or capsaicin-like compounds to repel mammals, while at the same time permitting birds to disperse seeds.

But, there are many irritants and there is remarkably little work on comparative aspects of their receptor physiology. Based on what is known of other chemical senses (see below on taste), it is likely that there will be discoveries of major species differences that, like the bird vs. mammal example, could be exploited in the development of repellents. Indeed, recent studies (Park et al. 2008) have shown that blind mole rats are insensitive

to capsaicin and acids, even though they have a sensitive receptor. Apparently, there have been changes in the central nervous system rendering them insensitive to these irritants, perhaps because they live in large groups in burrows where irritants naturally build up.

Molecular-cellular techniques are now available to look for species differences using isolated cell-based systems that do not initially require expensive and difficult whole animal testing. Such assay and screening systems can be both predictive and cost effective.

Olfaction

One of the long-term interests in odor communication in vertebrates has been in pheromone biology. Early work with insects suggested that it might be possible to attract or repel pest species, and much similar work continues. For vertebrates, many more difficulties have been encountered in using pheromones for practical purposes. However, now that we are beginning to understand how odors, particularly those that convey socially relevant messages, are detected and processed, this may change.

Our interests in odor communication at Monell have focused on odors indicative of individual identity and disease (Willse et al. 2005, Beauchamp and Yamazaki 2002). There has long been an interest in the possibility of training animals, particularly dogs, to diagnose human disease (see review by Gordon et al. 2008). Using odors to diagnose diseases in other animals follows logically from this. We and others have shown that animals with certain infections and diseases can be identified by an odor associated with the disease. Our ongoing studies have focused on the potential to detect virus-infected mice (Yamazaki et al. 2002). In these studies, we have shown that mice infected with mouse mammary tumor virus express an odor that allows other mice to identify them as infected; current studies are designed to investigate the chemistry of these odor signals as well as the specificity and generality of olfactory diagnosis of disease.

Presuming progress in use of odors for disease diagnosis, the next step will be to develop instruments that can do the same thing. Development of novel sensor devices using detectors such as DNA fragments, pheromone-binding proteins, and immobilized odor receptors promises to provide breakthroughs in our ability to detect and monitor disease vectors in the natural environment.

Taste

One of the most surprising findings from recent comparative studies of taste receptors has been their diversity. It has long been known from behavioral studies that animal species vary in their sensitivity and preference for taste compounds. Presumably, species have evolved to reflect their ecological niches, in this case reflecting available nutrients and potential poisons. Receptor-based differences in bitter taste sensitivity should provide scope for identifying particularly powerful repellents. As noted above, development of receptor-based screening tools for use prior to testing whole animals will provide researchers with a particularly powerful tool.

Similarly, appetitive tastes vary according to the ecological niche of a species. Many years ago, we reported (Beauchamp et al. 1977) that cats have no preferences for sweet carbohydrates, as might be expected for an obligate carnivore. Recently, we showed (Li et al. 2005) that this was due to an evolutionary change in one of the receptor genes involved in producing the sweet receptor: the cat gene has been pseudogenized presumably as a result of relaxed selection. Analogous events may have happened several times in strictly carnivorous species and even in much more primitive organisms, as has been recently demonstrated with yeasts (Hittinger et al. 2004). We are now conducting a screen of many more carnivorous species, both behaviorally and genetically, to provide a better sampling of how sweet taste receptors have evolved in the face of different ecological settings and different diet choices. A more complete understanding of the molecular biology of taste receptors in a species of interest, be it an endangered animal, or a pest such as a pig or deer or coyote, should help in designing novel and effective repellents and attractants.

CONCLUSIONS

In the future, we will discover more about how the chemical senses (as well as other senses) are organized and how the brain processes the information. In this presentation, the three chemical senses were discussed as if each stood alone. But in the real world, most foods, flavors, and body odors consist of mixtures of tastes, odors, and chemesthetic agents. Much additional work will be needed to understand the interactions among the senses.

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