The Egyptian Journal of Medical Human Genetics (2013) **14**, 367–373

Ain Shams University

**The Egyptian Journal of Medical Human Genetics**

www.ejmhg.eg.net
www.sciencedirect.com

ORIGINAL ARTICLE

# Distribution of sensory taste thresholds for phenylthiocarbamide (PTC) taste ability in North Indian Muslim populations

**Ruqaiya Hussain, Ahsana Shah, Mohammad Afzal** *

*Human Genetics and Toxicology Lab, Section of Genetics, Department of Zoology, Aligarh Muslim University, Aligarh, Uttar Pradesh 202002, India*

Received 6 May 2013; accepted 19 June 2013
Available online 25 July 2013

**KEYWORDS**

Phenylthiocarbamide (PTC);
Bitter taste perception;
Bimodal distribution;
Serial dilution method;
North Indian Muslims

**Abstract** The ability to taste Phenylthiocarbamide (PTC), a bitter organic compound has been described as a bimodal autosomal trait in both genetic and anthropological studies. This study is based on the ability of a person to taste PTC. The present study reports the threshold distribution of PTC taste sensitivity among some Muslim populations of North India, as till now no detailed information is available. A survey was conducted among healthy individuals within the age range of 10–45 years who were randomly selected from among six populations viz; Syed, Sheikh, Pathan, Ansari, Qureshi and Saifi. The PTC tasting ability was measured using a serial dilution method of Harris and Kalmus. A bimodal distribution was observed from the graphs plotted for the PTC threshold distribution. The mean PTC threshold values (±SD) of the male and female individuals were calculated as 8.12 ± 0.21 and 8.39 ± 0.20, respectively. The threshold values among the six populations ranged from 7.71 to 8.81 among males, 7.44–9.04 among females and 7.86–8.91 as combined. The results found that females show a higher mean threshold value than males, though of no statistical significance. This type of study will provide brief information on the distribution of PTC sensory thresholds among some Muslim populations of North India. This study has some physiological relevance to highlight the adaptability of endogamous groups to behavioral traits in the same place.



## 1. Introduction

Researches in human population genetics have been carried out by several investigators and significant information concerning mutation, selection, random genetic drift, inbreeding, protein polymorphism and association between genetic markers and diseases in different regions of the world have been obtained [1–3].

* Corresponding author. Tel.: +91 05712700920, mobile: +91 9897839601; fax: +91 571 2707944/571 2701239.
E-mail address: afzal1235@rediffmail.com (M. Afzal).

Peer review under responsibility of Ain Shams University.

Production and hosting by Elsevier

1110-8630 © 2013 Production and hosting by Elsevier B.V. on behalf of Ain Shams University.
http://dx.doi.org/10.1016/j.ejmhg.2013.06.003

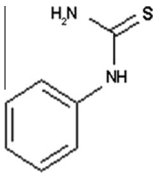


**Figure 1** Chemical structure of phenylthiocarbamide.

Little is known about the genetic structure and genetic distance of Muslims in India. They belong to two major sects: Sunnis and Shias, each sect has different endogamous groups, grouped under Ashraf and Ajlaf [4]. The former is comprised of higher rank Muslims like Syeds, Sheikhs, Pathans and Mughals while the latter is comprised of Ansaris, Qureshis and Saifis. A large number of the Ajlaf may also be converts from local indigenous populations of other faiths [5,6]. Though there is no caste system in Islam, it is the social isolation that led to differentiation of groups over many generations including the difference in the gene pools. The endogamous groups among Ashrafs and Ajlafs generally do not intermarry among themselves, thus having distinct gene pools.

Bitter perception generally occurs through bitter taste receptors located on the surface of taste cells of the tongue [7]. These receptors are encoded by T2R genes that show 25–89% of amino acid sequence identity among the 25 different members of this gene family. These differences presumably allow a wide variety of different chemical shapes, sizes, and functionalities to bind these receptors and be perceived as bitter. Psychophysical studies have showed that large individual differences in the bitterness of taste compounds exist [8]. The best known example of variation in sensitivity to a bitter compound is that of phenylthiocarbamide (PTC) (Fig. 1).

Phenylthiocarbamide (PTC), a bitter chemical synthesized by Fox [9] and has been widely used for genetic and anthropological studies [10]. Bitter-taste perception is a classically variable trait both within and between human populations [11].

The inability to taste PTC is a simple Mendelian recessive trait [12–16] wherein the individuals with two recessive alleles (tt) are non tasters for PTC and individuals with one dominant allele (Tt) or two dominant alleles (TT) are tasters for PTC. Virtually, all human populations studied to date display bimodality in sensitivity to PTC, such that approximately 75% of individuals worldwide perceive this compound as intensely

**Table 1** Threshold distribution of PTC trait among males of total population among North Indian Muslims.

| Solution no. | Syed | % | Sheikh | % | Pathan | % | Ansari | % | Qureshi | % | Saifi | % | Total | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | – | – | – | – | – | – | – | – | – | – | – | – | 1 | 0.5 |
| 2. | – | – | 1 | 2.6 | 1 | 1.7 | – | – | – | – | – | – | 3 | 1.5 |
| 3. | – | – | 1 | 2.6 | 1 | 1.7 | – | – | – | – | – | – | 4 | 2.0 |
| 4. | 3 | 7.5 | 3 | 7.8 | 3 | 5.1 | – | – | 2 | 6.4 | 1 | 4.7 | 10 | 5.0 |
| 5. | 6 | 15.0 | 4 | 10.5 | 5 | 8.6 | 3 | 10.3 | 3 | 9.6 | 2 | 9.5 | 20 | 10.0 |
| 6. | 7 | 17.5 | 6 | 15.7 | 10 | 17.2 | 4 | 13.7 | 2 | 6.4 | 5 | 23.8 | 30 | 15.0 |
| 7. | 4 | 10.0 | 4 | 10.5 | 8 | 13.7 | 5 | 17.2 | 4 | 12.9 | 3 | 14.2 | 28 | 14.0 |
| 8. | 4 | 10.0 | 4 | 10.5 | 6 | 10.3 | 3 | 10.3 | 4 | 12.9 | 3 | 14.2 | 26 | 13.0 |
| 9. | 4 | 10.0 | 2 | 5.2 | 4 | 6.8 | 4 | 13.7 | 3 | 9.6 | 1 | 4.7 | 15 | 7.5 |
| 10. | 3 | 7.5 | 1 | 2.6 | 3 | 5.1 | 2 | 6.8 | 2 | 6.4 | 3 | 14.2 | 10 | 5.0 |
| 11. | 2 | 5.0 | 5 | 13.1 | 4 | 6.8 | 3 | 10.3 | 4 | 12.9 | 2 | 9.5 | 14 | 7.0 |
| 12. | 4 | 10.0 | 4 | 10.5 | 6 | 10.3 | 4 | 13.7 | 5 | 16.1 | 1 | 4.7 | 19 | 9.5 |
| 13. | 1 | 2.5 | 1 | 2.6 | 3 | 5.1 | – | – | 1 | 3.2 | – | – | 11 | 5.5 |
| 14. | 2 | 5.0 | 2 | 5.2 | 4 | 6.8 | 1 | 3.4 | 1 | 3.2 | – | – | 8 | 4.0 |
| Total | 40 | | 38 | | 58 | | 29 | | 31 | | 21 | | 199 | |

**Table 2** Threshold distribution of PTC trait among females of total population among North Indian Muslims.

| Solution no. | Syed | % | Sheikh | % | Pathan | % | Ansari | % | Qureshi | % | Saifi | % | Total | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | – | – | – | – | 2 | 3.2 | – | – | – | – | – | – | 1 | 0.4 |
| 2. | – | – | – | – | 2 | 3.2 | – | | – | – | – | – | 1 | 0.4 |
| 3. | 1 | 3.0 | 1 | 2.7 | 3 | 4.8 | – | – | 1 | 3.8 | 2 | 8.6 | 6 | 2.7 |
| 4. | 1 | 3.0 | 1 | 2.7 | 2 | 3.2 | 2 | 9.5 | 1 | 3.8 | 1 | 4.3 | 11 | 5.0 |
| 5. | 2 | 6.0 | 2 | 5.4 | 6 | 9.6 | 1 | 4.7 | – | – | 1 | 4.3 | 18 | 8.1 |
| 6. | 5 | 15.1 | 5 | 13.5 | 12 | 19.3 | 2 | 9.5 | 2 | 7.6 | 4 | 17.3 | 34 | 15.4 |
| 7. | 6 | 18.1 | 5 | 13.5 | 11 | 17.7 | 5 | 23.8 | 2 | 7.6 | 3 | 13.0 | 31 | 14.0 |
| 8. | 4 | 12.1 | 2 | 5.4 | 6 | 9.6 | 3 | 14.2 | 6 | 23.0 | 1 | 4.3 | 20 | 9.0 |
| 9. | 2 | 6.0 | 2 | 5.4 | 2 | 3.2 | 1 | 4.7 | 4 | 15.3 | 1 | 4.3 | 15 | 6.8 |
| 10. | 1 | 3.0 | 3 | 8.1 | 2 | 3.2 | 2 | 9.5 | 2 | 7.6 | 2 | 8.6 | 16 | 7.2 |
| 11. | 3 | 9.0 | 2 | 5.4 | 4 | 6.4 | 1 | 4.7 | 2 | 7.6 | 4 | 17.3 | 22 | 10.0 |
| 12. | 3 | 9.0 | 5 | 13.5 | 4 | 6.4 | 2 | 9.5 | 3 | 11.5 | 1 | 4.3 | 23 | 10.4 |
| 13. | 4 | 12.1 | 2 | 5.4 | 3 | 4.8 | 2 | 9.5 | 2 | 7.6 | 2 | 8.6 | 10 | 4.5 |
| 14 | 1 | 3.0 | 4 | 10.8 | 3 | 4.8 | – | – | 1 | 3.8 | 1 | 4.3 | 12 | 5.4 |
| Total | 33 | | 37 | | 62 | | 21 | | 26 | | 23 | | 220 | |

**Table 3** Threshold distribution of PTC trait among combined total population among North Indian Muslims.

| Solution no. | Syed | % | Sheikh | % | Pathan | % | Ansari | % | Qureshi | % | Saifi | % | Total | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | – | – | – | – | 2 | 1.6 | – | – | – | – | – | – | 2 | 0.4 |
| 2. | – | – | 1 | 1.3 | 3 | 2.5 | – | – | – | – | – | – | 4 | 0.9 |
| 3. | 1 | 1.3 | 2 | 2.6 | 4 | 3.3 | – | – | 1 | 1.7 | 2 | 4.5 | 10 | 2.3 |
| 4. | 4 | 5.4 | 5 | 6.6 | 5 | 4.1 | 2 | 4.0 | 3 | 5.2 | 2 | 4.5 | 21 | 5.0 |
| 5. | 8 | 10.9 | 9 | 12.0 | 11 | 9.1 | 4 | 8.0 | 3 | 5.2 | 3 | 6.8 | 38 | 9.0 |
| 6. | 12 | 16.4 | 11 | 14.6 | 22 | 18.3 | 6 | 12.0 | 4 | 7.0 | 9 | 20.4 | 64 | 15.2 |
| 7. | 10 | 13.6 | 8 | 10.6 | 19 | 15.8 | 10 | 20.0 | 6 | 10.5 | 6 | 13.6 | 59 | 14.0 |
| 8. | 8 | 10.9 | 6 | 8.0 | 12 | 10.0 | 6 | 12.0 | 10 | 17.5 | 4 | 9.0 | 46 | 10.9 |
| 9. | 6 | 8.2 | 4 | 5.3 | 6 | 5.0 | 5 | 10.0 | 7 | 12.2 | 2 | 4.5 | 30 | 7.1 |
| 10. | 4 | 5.4 | 4 | 5.3 | 5 | 4.1 | 4 | 8.0 | 4 | 7.0 | 5 | 11.3 | 26 | 6.2 |
| 11. | 5 | 6.8 | 7 | 9.3 | 8 | 6.6 | 4 | 8.0 | 6 | 10.5 | 6 | 13.6 | 36 | 8.5 |
| 12. | 7 | 9.5 | 9 | 12.0 | 10 | 8.3 | 6 | 12.0 | 8 | 14.0 | 2 | 4.5 | 42 | 10.0 |
| 13. | 5 | 6.8 | 3 | 4.0 | 6 | 5.0 | 2 | 4.0 | 3 | 5.2 | 2 | 4.5 | 21 | 5.0 |
| 14. | 3 | 4.1 | 6 | 8.0 | 7 | 5.8 | 1 | 2.0 | 2 | 3.5 | 1 | 2.2 | 20 | 4.7 |
| Total | 73 | | 75 | | 120 | | 50 | | 57 | | 44 | | 419 | |

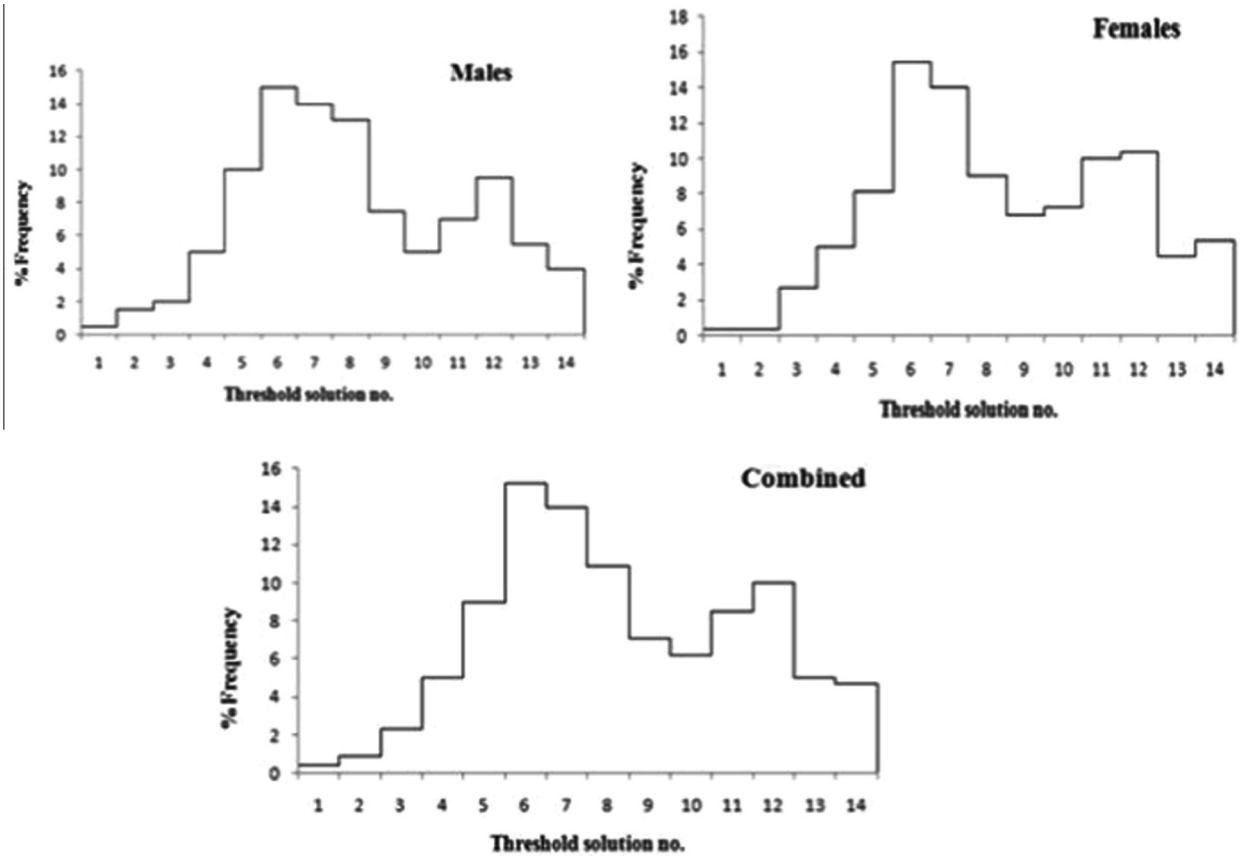


**Figure 2** Graph showing threshold distribution of PTC trait among males, females and combined population groups.

bitter, while to others, this compound is relatively tasteless. This difference has led to the use of PTC in many studies on taste perception in humans [17,18] and over the past 70 years, these studies have provided many insights into the study of human psychophysics and physiology.

Kim et al. [10] have identified that a small region on Chromosome 7q has a gene that encodes a member of the TAS2R bitter taste receptor family. A major locus on 7q35–q36 and a secondary locus on Chromosome 16p have been localized by genome scan for PTC taster gene [19]. Bufe et al. [20] demonstrated that alleles of hTAS2R38 code for functionally different receptor types that directly affect perception of bitterness containing compounds. The ability to taste PTC is a dominant genetic trait, and the test to determine PTC sensitivity is one of the most commonly used genetic tests on humans. Many workers have reported that human populations show a tremendous variation in the frequency of tasters which ranges from 10% to 98% [21]. Identification of PTC gene has provided the basis for a new, integrative investigation of PTC taste sensitivity [22].

**Table 4** Combined threshold chart of tasters for different Muslim populations of North India.

| Population | Male | | | Female | | | Combined | | |
|---|---|---|---|---|---|---|---|---|---|
| | Sample size | Modal value (6–12) | X ± SE | Sample size | Modal value (6–12) | X ± SE | Sample size | Modal value (6–12) | X ± SE |
| Syed | 40 | 6 | 8.53 ± 0.42 | 33 | 7 | 8.5 ± 0.51 | 73 | 6 | 8.24 ± .35 |
| Sheikh | 38 | 6 | 8.03 ± 0.52 | 37 | 5 | 8.70 ± 0.55 | 75 | 6 | 8.36 ± .38 |
| Pathan | 58 | 6 | 8.33 ± 0.41 | 62 | 6 | 7.44 ± 0.41 | 120 | 6 | 7.86 ± .29 |
| Ansari | 29 | 7 | 8.59 ± 0.46 | 21 | 7 | 8.29 ± 0.60 | 50 | 7 | 8.46 ± .36 |
| Qureshi | 31 | 12 | 8.81 ± 0.50 | 26 | 8 | 9.04 ± 0.53 | 57 | 8 | 8.91 ± .36 |
| Saifi | 21 | 6 | 7.71 ± 0.49 | 23 | 6 | 8.39 ± 0.91 | 44 | 6 | 8.07 ± .42 |
| Combined | 199 | 6 | 8.12 ± 0.21 | 220 | 6 | 8.39 ± 0.20 | 419 | 6 | 8.26 ± .14 |

X = Mean.
SE = Standard error.

Some studies on Muslim populations have been attempted earlier in Uttar Pradesh [23]. Hence in the present study we made an attempt to analyze the threshold distribution for phenylthiocarbamide among some Muslim populations of North India. Males and Females of different populations have also been compared for the taste sensitivity of this trait.

## 2. Materials and methods

Subjects (both sexes) belonging to different populations of Uttar Pradesh, North India were observed for phenylthiocarbamide taste sensitivity. A survey was conducted among healthy individuals within the age range of 10–45 years who were randomly selected from six populations viz; Syed, Sheikh, Pathan, Ansari, Qureshi and Saifi.

The method to distinguish tasters from non-tasters was adopted as per the sorting technique of serial dilutions of Harris and Kalmus [16], because of its superiority in discerning the threshold level of the individual with near perfection.

A solution of 0.13% of PTC was prepared by dissolving 130 mg of the material in 100 ml of water (solution 14). The serial dilution from 1 through 14 was prepared taking 50 ml of solution and adding 50 ml of distilled water to it to make the solution 13 which is diluted to half of 14. The last solution was the most dilute and designated as solution no. 1. The dilution is used for noting the threshold value. The dilution number when tasted positive was recorded. If an individual did not taste even the solution 14 (strongest), he was designated as non-taster. After the test, the participant was asked to spit out the chemical and rinse the mouth with water. Information on caste, sect, consanguinity and biradari was noted. Threshold levels for PTC were then recorded for males and females of each population. The distribution of the frequency of tasters and non-tasters is usually bimodal with antimode recording the lowest frequency separating the two distributions. The

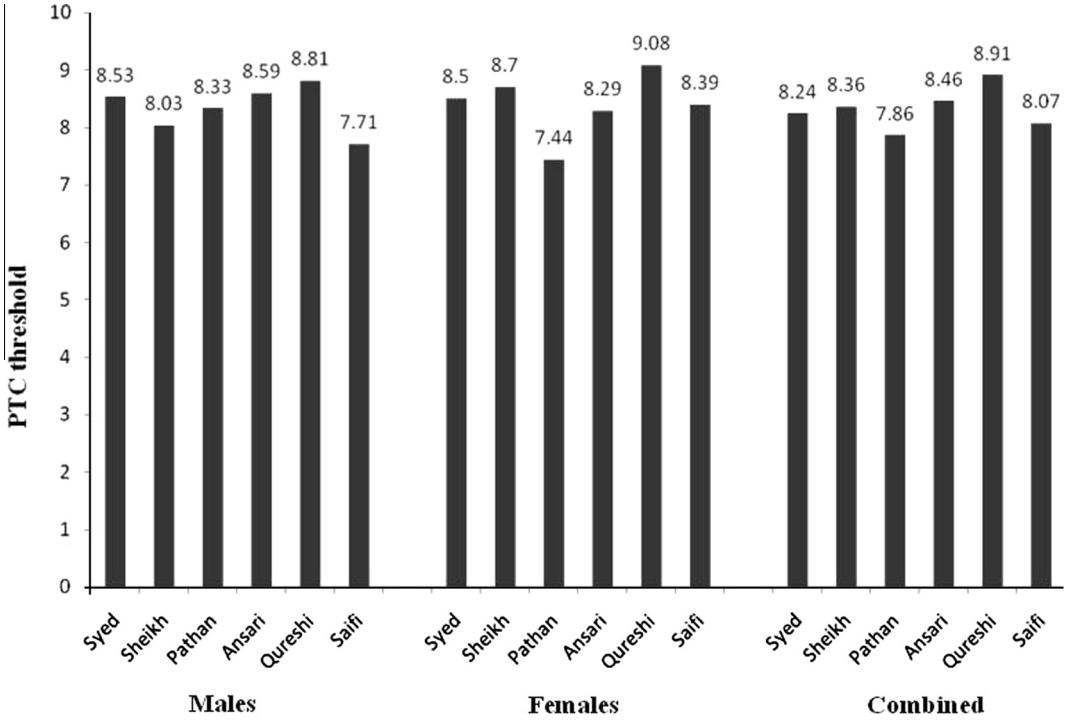


**Figure 3** Graph showing mean threshold values of males, females and combined populations for PTC trait.

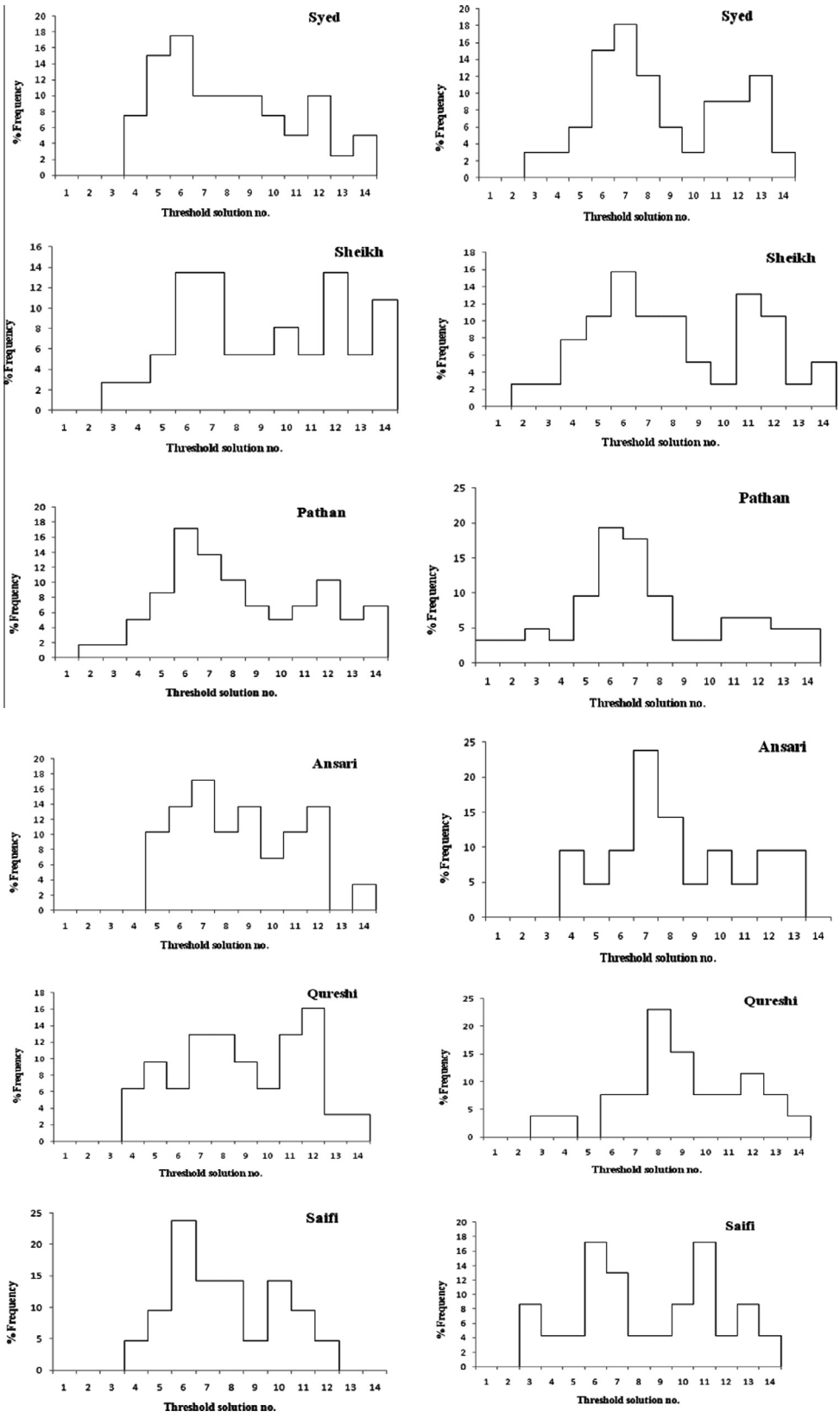


**Figure 4** Graph showing frequency distribution of thresholds of PTC among different population groups. Males on the left and females on the right.

anitmodal point was taken to classify the subjects as tasters or non-tasters.

## 3. Results

The frequency distribution of the various threshold levels of PTC taste sensitivity among the males, females and combined populations is given (Tables 1–3). A well-defined bimodal distribution of the taste sensitivity was observed in all the communities investigated as shown (Fig. 2). The modes among the tasters were characterized by sharp peaks of solution no. 6 and the antimode lies on solution no. 7 among males, females and combined population groups of Muslims. The means and standard errors of the thresholds for males, females and combined population groups were calculated as $8.12 \pm 0.21$, $8.39 \pm 0.20$, $8.26 \pm 0.15$, respectively (Table 4). Fig. 3 presents the threshold values among six populations which ranged from 7.71 to 8.81 in males, 7.44–9.04 in females and 7.86–8.91 as combined. The Qureshi shows the highest ones (8.81 in males and 9.04 in females), Pathan the lowest (8.33 in males and 7.44 in females) and Syed, Sheikh, Ansari and Saifi showed intermediate threshold values. In overall population, it is interesting to note that the females show a higher mean threshold value than males.

The populationwise distribution of thresholds is shown graphically in Fig. 4 where the frequencies, expressed as percentages of the total for each sex, are plotted against the threshold.

## 4. Discussion

The sense of taste is a strong predictor of food selection. Human infants show an innate pleasure response to sweet taste, but dislike and reject bitter-tasting foods [24]. In 1931 Fox [25] observed that to some individuals, the simple chemical compound phenylthiocarbamide (PTC), has an intensely bitter taste, while to others it is tasteless. Being a chemist he also showed that a number of other closely related substances are tested well by the PTC tasters but not by the non-tasters. The ability to taste these substances was shown by Blaklee [26] and by Synder [27] to behave as a Mendelian dominant character.

Two major forms of this bitter receptor gene were identified in most of the world's populations, designated as the 'major taster' form the 'major non-taster' form. These two forms differ in 3 amino acid positions, numbers 49, 262, and 296 [28].

Previous investigators noted that people who were less sensitive to this class of bitter compounds seemed to lose their sensitivity faster as they got older, concluding that gene penetrance might differ by age and genotype [29].

The ability or inability to taste the PTC is a classic inherited trait that has long been known to vary in human population. This trait is of genetic, epidemiologic and evolutionary interest and has been shown to correlate with a number of dietary preferences and thus has important implications for human health [14,12,20].

Harris and Kalmus [16] found that the distribution of PTC tasting thresholds was bimodally distributed, but there were some intermediate individuals. Other studies have found similar results, a bimodal distribution with some intermediate individuals [26,30,31,29].

Reddy and Rao [32] re-examined the genetics of PTC taste thresholds by studying 100 nuclear families. They concluded that variability in thresholds is controlled by a major locus with incomplete dominance as well as by a multifactorial component.

The sorting technique with serial dilution method of Harris and Kalmus [16] is considered by most investigators a much more precise tool of measurement. Nearly every population shows a bimodal distribution of thresholds with a clear-cut intermediate dilution level after which threshold falls. Those who can taste solutions diluted more than this critical value are classified as tasters and those whose thresholds fall below the lowest concentration are non-tasters. By this technique, the separation point between tasters and non tasters lies between dilutions 6 and 7.

As shown in Fig. 2 recognition of threshold distribution for PTC among 199 males and 220 females showed bimodal distribution. The present investigation of this study shows that the PTC taste thresholds vary among six population groups of Muslims, the females showed higher mean threshold value than males. The mean thresholds, standard deviations and modal values among males, females and combined groups have interesting features. In nearly all population groups, the mode and antimode lie between the solution number 6 and 7 for both males and females, with the exception of Ansari and Qureshi populations in which Ansaris show the mode and antimode lying between the solution number 7 and 8 while among Qureshis the mode and the antimode lie between the solution number 8 and 9, for both male and female population groups.

Genetic approaches are rapidly yielding new information about our sense of taste. Our understanding of bitter taste has increased considerably with the discovery and study of T2R family of taste receptor genes, their genetic linkage and positional cloning studies and from studies on inherited variation in the ability to taste phenylthiocarbamide (PTC). The Sweet and Umami tastes are mediated by T1R receptors and are being studied actively. Salty and sour tastes are still poorly studied in genetic terms and represent opportunities for the future research [28]. Besides its importance in genetic and anthropological studies, PTC taste sensitivity has been shown to be important in food selection, which may affect individual metabolism and physiology [33]. It was previously used in paternity testing before the advent of DNA markers [34].

On a larger scale, the PTC gene may be illustrative of ancient genetic variation that has been proposed to underlie common disease in modern populations [35]. In addition, the mapping of the PTC genes will provide a powerful tool to examine the genetic basis for food preferences and the relationship between taste status and health outcomes [17]. Finally, PTC presents a unique opportunity for the field of bitter taste transduction. Having a known gene with a strong effect on phenotype in vivo provides many opportunities for studies of taste physiology, biochemical function, and molecular structure elucidation in case of human sense of taste. Such studies have a great significance in understanding the adaptability of the populations to the same region which results in their varying response to threshold of sensitivity of the same genetic trait. More such traits will be useful in looking at this problem if studied in detail.

## 5. Conclusion

The present paper reports the threshold distribution of PTC taste perception among some Muslim populations of North India. Our results revealed that females show a higher mean threshold value than males, but this is of no statistical consequence. Although

PTC itself has not been found in nature, the ability to taste PTC is correlated strongly with the ability to taste other naturally occurring bitter substances, many of which are toxic [36,37]. Thus, understanding the nature of the variation in bitter taste perception and its relationship to diet and other behavior aspects may have important implications for human health [38].

## Conflict of interest

The authors declare that there is no conflict of interest.

## Acknowledgements

Thanks are due to the University Grant Commission, New Delhi, India for awarding UGC Maulana Azad National Fellowship to the first author Ruqaiya Hussain (No. F1-17.1/2012-13) and to the Chairman, Department of Zoology, A.M.U., Aligarh (U.P), India, for laboratory facilities. We are also grateful to the volunteers and study subjects for their kind participation and cooperation during this study.

## References

[1] Cavalli-Sforza LL. Analytic review: some current problems of human population genetics. Am J Hum Genet 1973;25:82–104.
[2] Cavalli-Sforza LL. The DNA Revolution in population genetics. Trends Genet 1998;14:60–5.
[3] Penrose LS. Human variability and adaptability. In: Roberts DF, editor. Human Variation and Natural Selection. London: Taylor Francis Ltd; 1975.
[4] Ansari G. Muslim Caste in UP. Lucknow: Ethnographic and Folk Culture and Soc; 1959.
[5] Ahmad I. Endogamy and status mobility among the Siddique, Sheikhs of Allahbad, UP. In: Ahmad I, editor. Caste and Stratification among the Muslims of India. Delhi: Manohar; 1978. p. 171–206.
[6] Afzal M, Sinha SP. Consanguinity effects on the frequency of ABO blood group, PTC taste ability, and red-green color blindness. Biol Bull India 1983;5:182–5.
[7] Adler E, Hoon MA, Mueller KL, Chandrashekar J, Ryba NJ, Zuker CS. A novel family of mammalian taste receptors. Cell 2000;100:693–702.
[8] Delwiche JF, Buletic PA, Breslin PA. Covariation in individuals' sensitivities to bitter compounds: evidence supporting multiple receptor/transduction mechanisms. Percept Psychophys 2001;63:761–76.
[9] Fox AL. Taste blindness. Science 1931;73:14.
[10] Kim V, Jorgenson E, Coon H, Leppert M, Risch N, Drayna D. Positional cloning of the human quantitative trait locus underlying taste sensitivity to phenylthiocarbamide. Science 2003;299:1221–5.
[11] Tepper BJ, Nurse RJ. PROP taster status is related to fat perception and preference. Ann N Y Acad Sci 1998;855:802–4.
[12] Kim UK, Drayna D. Genetics of individual differences in bitter taste perception: lessons from the PTC gene. Clin Genet 2005;67:275–80.
[13] Reed DR. Progress in human bitter phenylthiocarbamide genetics. In: Prescott J, Tepper BJ, Dekker M, editors. Genetic Variation in Taste Sensitivity. New York; 2004. p. 43–62.
[14] Wooding S, Kim U, Bamshad MJ, Larsen J, Jorde LB, Drayna D. Natural selection and molecular evolution in PTC, a bitter-taste receptor gene. Am J Hum Genet 2004;74:637–46.
[15] Hartmann G. Application of individual taste differences towards Phenylthio-carbamide in genetic investigations. Ann Eugen 1939;9:123–35.
[16] Harris H, Kalmus H. The measurement of taste sensitivity to phenylthiourea (PTC). Ann Eugen 1949;15:24–31.
[17] Guo SW, Reed DR. The genetics of phenylthiocarbamide perception. Ann Hum Biol 2001;28:111–42.
[18] Tepper BJ. 6-n-Propylthiouracil: a genetic marker for taste, with implications for food preference and dietary habits. Am J Hum Genet 1998;63:1271–6.
[19] Drayna D, Coon H, Kim UK, Elsner T, Cromer K, Otterud B. Genetic analysis of a complex trait in the Utah genetic reference project: a major locus for PTC taste ability on chromosome 7q and a secondary locus on chromosome 16p. Hum Genet 2003;112:567–72.
[20] Bufe B, Breslin PA, Kuhn C, Reed DR, Tharp CD, Slack JP. The molecular basis of individual differences in phenylthiocarbamide and propylthio-uracil bitterness perception. Curr Biol 2005;15:322–7.
[21] Pal SK, Sharma K, Pathak A, Sawhney IM, Prabhakar S. Possible relationship between phenylthiocarbamide taste sensitivity and epilepsy. Neurol India 2004;52:206–9.
[22] Wooding S. Phenylthiocarbamide: a 75 year adventure in genetics and natural selection. Genetics 2006;172:2015–23.
[23] Ruqaiya H, Fareed M, Ahsana S, Afzal M. Prevalence and gene frequencies of $A_1A_2BO$ and Rh(D) blood group alleles among some Muslim populations of North India. Egypt J Med Hum Genet 2013;14:69–76.
[24] Rozin P, Vollmecke TA. Food likes and dislikes. Annu Rev Nutr 1986;6:433–56.
[25] Fox AL. The relationship between chemical constitution and taste. Proc Natl Acad Sci USA 1932;18:115–20.
[26] Blakeslee AF. Genetics of sensory thresholds: taste for phenylthiocarbamide. Proc Natl Acad Sci USA 1932;18:120–30.
[27] Synder LH. Studies in human inheritance. IX. The inheritance of taste deficiency in man. Ohio J Science 1932;32:436–40.
[28] Kim UK, Breslin PA, Reed D, Drayna D. Genetics of human taste perception. J Den Res 2004;3:448–53.
[29] Whissell-Buechy D. Effects of age and sex on taste sensitivity to phenylthiocarbamide (PTC) in the Berkeley Guidance sample. Chem Senses 1990;15:39–57.
[30] Salmon TN, Blakeslee AF. Genetics of sensory thresholds: variations within single individuals in taste sensitivity for PTC. Proc Natl Acad Sci USA 1935;21:78–83.
[31] Olson JM, Boehnke M, Neiswanger K, Roche AF, Siervogel RM. Alternative genetic models for the inheritance of the phenylthiocarbamide taste deficiency. Genet Epidemiol 1989;6:423–34.
[32] Reddy BM, Rao DC. Phenylthiocarbamide taste sensitivity revisited: complete sorting test supports residual family resemblance. Genet Epidemiol 1989;6:413–21.
[33] Davis RG. Increase bitter taste detection in Yucatan inhabitants related to coffee as a dietary source of niacin. Chem Senses 1978;3:423–9.
[34] Cardullo H, Holt LJ. Ability of infants to taste PTC: its application in cases of doubtful paternity. Proc Soc Exp Biol Med 1951;76:589–92.
[35] Mourao LA, Salzano FM. New data on the association between PTC tasting and tuberculosis. Rev Bras Biol 1978;38:475–9.
[36] Bergen AW, Caporaso N. Cigarette smoking. J Nat Cancer Inst 1999;91:1365–75.
[37] Enoch MA, Harris CR, Goldman D. Does a reduced sensitivity to bitter taste increase the risk of becoming nicotine addicted. Addic Behav 2001;26:399–404.
[38] Malini SS, Ramegowda S, Ramachandra NB. Evolution of phenylthiocarbamide taster trait in Mysore, South India. Indian J Hum Genet 2007;13:16–20.