



OPINION ARTICLE

Phytoglobin: a novel nomenclature for plant globins accepted by the globin community at the 2014 XVIII conference on Oxygen-Binding and Sensing Proteins [version 1; referees: 2 approved]

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Abstract

Hemoglobin (Hb) is a heme-containing protein found in the red blood cells of vertebrates. For many years, the only known Hb-like molecule in plants was leghemoglobin (Lb). The discovery that other Hb-like proteins existed in plants led to the term “nonsymbiotic Hbs (nsHbs)” to differentiate them from the Lbs. While this terminology was adequate in the early stages of research on the protein, the complexity of the research in this area necessitates a change in the definition of these proteins to delineate them from red blood cell Hb. At the 2014 XVIII Conference on Oxygen-Binding and Sensing Proteins, the group devoted to the study of heme-containing proteins, this issue was discussed and a consensus was reached on a proposed name change. We propose *Phytoglobin* (Phytogb) as a logical, descriptive name to describe a heme-containing (Hb-like) protein found in plants. It will be readily recognized by the research community without a prolonged explanation of the origin of the term. The classification system that has been established can essentially remain unchanged substituting Phytogb in place of nsHb. Here, we present a guide to the new nomenclature, with reference to the existing terminology and a phylogenetic scheme, placing the known Phytogbs in the new nomenclature.



This article is included in the [Oxygen-binding and sensing proteins](#) channel.

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- Kurt V Fagerstedt**, University of Helsinki Finland

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Hemoglobin (Hb) is a heme-containing protein found in the red blood cells of vertebrates¹. Hemoglobin-like proteins are also found in other tissues of vertebrates where they are given tissue-specific names that help to identify their locations and distinguish them from red blood cell Hb^{2,3}. For many years, the only known Hb-like molecule in plants was leghemoglobin (Lb), a protein induced as a result of the symbiotic relationship between legume plants and nitrogen-fixing bacteria⁴. The discovery that other Hb-like proteins existed in plants not capable of symbiotic relationships led to the term “nonsymbiotic Hbs (nsHbs)” to differentiate them from the Lbs⁵. While this terminology was adequate in the early stages of research on the protein, the complexity of the research in this area necessitates a change in the definition of these proteins to delineate them from red blood cell Hb, in keeping with the terminology for other Hb-like proteins, such as myoglobin in muscle, neuroglobin in neuron tissue and cytoglobin in vertebrate cell cytoplasm^{2,3}. In 2001 Hunt *et al.*⁶ classified plant Hbs as globin (GLB)0, GLB1, GLB2, GLB3 and GLB5 corresponding to undetermined (mostly liverwort and moss) nsHbs, angiosperm nsHbs class/type 1 and nsHbs class/type 2, truncated Hbs and symbiotic Hbs (which included

Lbs), respectively. However, an epithet for plant Hbs was absent in this nomenclature and distinctive characteristics for each category were not fully defined resulting in an incomplete classification system.

At the 2014 XVIII Conference on Oxygen-Binding and Sensing Proteins, the group devoted to the study of heme-containing proteins, the above issue was discussed and a consensus was reached on a proposed name change. *Phytoglobin* (*phyto*, plant; *globin*, heme-containing protein folding structurally similar to the sperm whale myoglobin structure whose heme-Fe is invariably coordinated at the proximal site by His F8), abbreviated as Phytogb, was proposed as a logical, descriptive name to describe a heme-containing (Hb-like) protein found in plants. It will be readily recognized by the research community without a prolonged explanation of the origin of the term, as is the case for ‘nonsymbiotic hemoglobin’. The classification system that has been established can essentially remain unchanged substituting Phytogb in place of nsHb. A guide to the new nomenclature, with reference to the existing terminology, is given in Table 1. A more detailed phylogenetic scheme, placing the known Phytogbs in the new nomenclature, is shown in Figure 1.

Table 1. System and characteristics of the accepted nomenclature for plant (algae + land plants) Phytoglobins (Phytogb).

Former plant globin name and abbreviation (in parenthesis)	New nomenclature ^a	Plant origin	Distinctive characteristics ^b
Nonsymbiotic hemoglobin (nsHb)	Phytogb0	Algae ^c +bryophytes+gymnosperms	Heme-Fe either penta- or hexacoordinate. Moderate to high affinity for O ₂ . Localized in any plant organ.
Class/type 1 nonsymbiotic hemoglobin (nsHb-1)	Phytogb1	Angiosperms	Heme-Fe predominantly hexacoordinated by a distal amino acid. Extremely high affinity for O ₂ mostly due to a very low O ₂ -dissociation rate constant (<i>k_{off}</i>). Localized in any plant organ.
Class/type 2 nonsymbiotic hemoglobin (nsHb-2)	Phytogb2	Angiosperms	Heme-Fe predominantly pentacoordinated. Moderate to high affinity for O ₂ . Localized in any plant organ.
Symbiotic hemoglobin (symHb)	SymPhytogb	Non-legume N ₂ -fixing plants ^d	Heme-Fe predominantly pentacoordinated. Moderate to high affinity for O ₂ . Specifically localized in N ₂ -fixing nodules of actinorhizal plants or any other non-legume land plant
Leghemoglobin (Lb)	Lb	N ₂ -fixing legumes ^d	Heme-Fe predominantly pentacoordinate. Moderate to high affinity for O ₂ . Specifically localized in legume N ₂ -fixing nodules.
Class/type 3 nonsymbiotic hemoglobin/ Truncated hemoglobin (tHb)	Phytogb3	Algae ^e +land plants	Globin-domain amino acid sequence and structure (i.e. folding into the 2/2-fold) similar to those of bacterial tHbs. Heme-Fe either penta- or hexacoordinate. Moderate to high affinity for O ₂ . Localized in any plant organ.

^aNumerical classification corresponds to that previously proposed by Hunt *et al.*⁶. Proteins coded by multiple *phytoglob* gene copy numbers within the same plant species should be indicated as the number of copy after the Phytogb numerical classification. For example, rice (*Oryza sativa*) Phytogbs 1 and 2 (corresponding to the former nsHbs-1) should be indicated as rice Phytogb1.1 and Phytogb1.2, respectively (see text for a description on the species-specific Phytogbs acronym).

^bHeme-Fe coordination and affinity for O₂ correspond to those from moss Phytogb0⁷⁻⁹, barley¹⁰, rice¹¹ and Arabidopsis¹² Phytogb1, Arabidopsis Phytogb2¹², *Casuarina* SymPhytogb¹³, soybean Lb^{14,15} and Arabidopsis Phytogb3¹⁶ representative of Phytogb0, Phytogb1, Phytogb2, SymPhytogb, Lb and Phytogb3, respectively.

^cAmino acid sequence of algal globins analyzed so far¹⁷⁻¹⁹ is similar to that of land plant Phytogb0 and Phytogb3, hence algal globins can be classified as Phytogb0 or Phytogb3, respectively.

^dSome SymPhytogbs and Lbs (such as the *Parasponia*²⁰ and *Casuarina*²¹ and *Chamaecrista*²² globins, respectively) are intermediate between Phytogbs1 and Phytogbs2 and Lbs^{22,23} because they exhibit amino acid sequence similarity to Phytogbs1 and Phytogbs2 (Figure 1) and are localized in non-legume legume nodules and apparently play a role in symbiotic N₂-fixation.

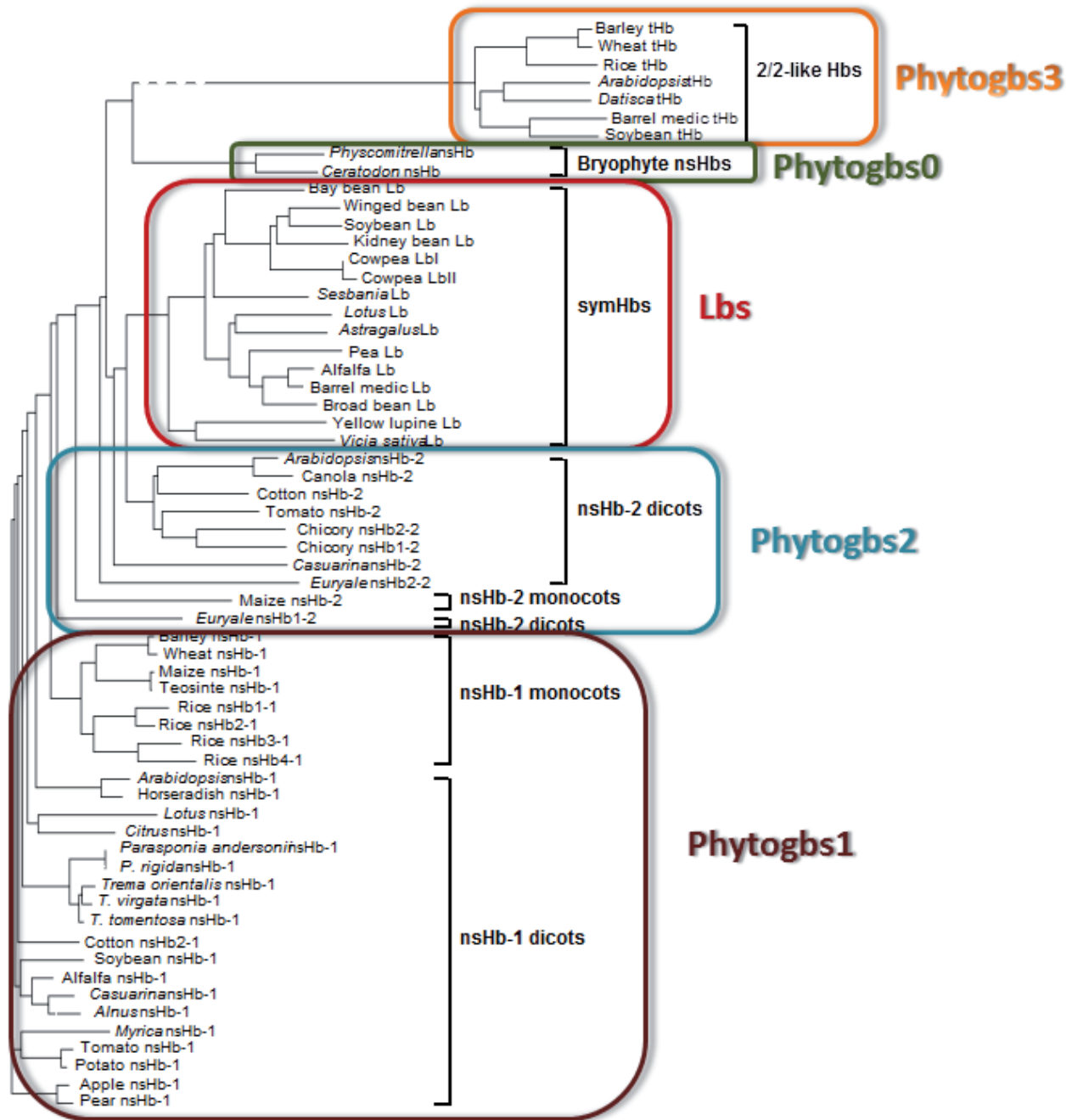


Figure 1. Phylogenetic representation of the novel nomenclature for land plant PhytoHbs. Note that *Parasponia*, *Casuarina*, *Alnus* and *Myrica* SymPhytoHbs are intermediate between SymPhytoHbs and PhytoHbs1 and PhytoHbs2 (see Table 1 for explanation). Figure modified from Garrocho-Villegas *et al.*²³ (reprinted with permission).

Also, we propose that acronym for the species-specific Phytogbs corresponds to the first three binomial (i.e. genus and species) letters followed by the Phytogb type and *phytogb* number of copy. For example, the acronym for rice (*Oryza sativa*) Phytogb1.1 (see [Table 1](#)) corresponds to OrysatPhytogb1.1.

Author contributions

RDH conceived the proposal. RDH, MSH and RAP discussed and proposed the novel nomenclature, prepared the first draft of the manuscript, revised the draft manuscript and have agreed to the final content.

Competing interests

No competing interests were disclosed.

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The change in the hemoglobin/phytoglobin nomenclature presented in Hill *et al.* paper is timely and well supported by the hemoglobin and phytoglobin community. The change has been discussed in many conferences including the 2014 XVIII Conference on Oxygen-Binding and Sensing Proteins mentioned in the paper. The system presented in Table 1 is logical and supported by the protein structures and by the phylogenetic tree presented in Figure 2. The only and very slight problem is in the positioning of symbiotic hemoglobins present in non-legume nitrogen fixing plants, which have amino acid sequence similarities with both Phytogbs1 and 2. However, their positioning as a separate group in Table 1 is supported by the fact that they are only found in the nodules of actinorhizal plants.

Dr. Topunov has provided a historical perspective on the evolution of the name phytoglobin in his referee report, which clearly shows both the need for the term and no scientific discrepancy in its use. I agree wholeheartedly.

I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Competing Interests: No competing interests were disclosed.

Referee Report 08 March 2016

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The reviewing article is dedicated to very interesting and actual issue. After proposition of the term “leghemoglobin” (Lb) by Virtanen and Laine (1946)¹ it was used only for hemoglobins (Hb) of the leguminous plants because it was the only one group of plants known to contain Hb. However after observing of Hbs in non-leguminous plants (Appleby *et al.* 1983², Tjepkema 1983³) the ironic situation originated. “Non-leguminous” hemoglobins are evolutionary closer to leghemoglobins, but according to their denominations they looked to be similar to animal ones. Even hemoglobin of cyanobacteria received its own specific denomination “cyanoglobin” (Hill *et al.* 1996)⁴ although it was initially illogically named

“Myoglobin in a cyanobacterium” (Potts *et al* 1992) ⁵, but plant Hbs were poor relatives in this family. The necessity of new terminology for plant hemoglobins appeared and such thoughts appared and were discussed.

The proposition of the new terminology “phytoglobin” (Phb) was already once stated. It was made in Bach Institute of Biochemistry (Moscow, Russia) in the book by Kretovich ⁶ and this term was even used in the published article (Topunov 1994) ⁷. This idea was not further developed at that time and in the next paper (Topunov 1995) ⁸ the old word “leghemoglobin” was employed again but using of the “phytoglobin” terminology in the article ⁷ was referred.

In conclusion: it is the right desire to revive this terminology for plant hemoglobins and it has to be promoted and continued. There is the one difference between these two propositions of the “phytoglobin” term. In 1990s it was used as the general terminology for all plant hemoglobins (from both leguminous and non-leguminous plants) ^{6,7} so “leghemoglobin” term could be excluded. Now it is proposed for plant hemoglobins aside from Lb, and it looks more pragmatic because scientists are accustomed to the “leghemoglobin” term and there is no need to exclude it from the scientific practice.

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I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Competing Interests: No competing interests were disclosed.

Author Response 08 Mar 2016

Raul Arredondo-Peter, Universidad Autonoma del Estado de Morelos, Mexico

We thank Dr. Topunov for his evaluation and providing information that complements the contents of this article.

Competing Interests: No competing interests were disclosed.

