**Self-assembly assisted kinetically controlled papain catalyzed formation of mPEG-*b*-Phe(Leu)$_x$**

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This work demonstrates protease catalyzed peptide synthesis is capable of forming a poly(ethylene glycol)-peptide (PEG-peptide) diblock copolymer by grafting leucine ethyl ester (Leu-OEt) from the C-terminus of methoxy poly(ethylene glycol)-phenylalanine ethyl ester (macroinitiator) in a one-pot aqueous reaction. The roles of buffer concentration, protease (and concentration), and feed ratio were examined on the efficiency of the grafting reaction along with the production of the oligo(Leu) co-product. Using papain catalysis [850 μM papain; 2.5 wt% macroinitiator; 8.2 to 1, Leu-OEt to macroinitiator feed ratio; pH 7.0-8.0; 1 h; 40°C] a macroinitiator efficiency of 66±4%, oligo(Leu) to PEG-peptide copolymer molar ratio of 0.86±0.09, and overall Leu-OEt conversion of 96±9% was observed. A narrowing of the (Leu)$_x$ peptide block in both co-products was also observed with dispersity's $\leq$1.02 in the diblock copolymer. Additionally, a clear preference for a degree of polymerization (*DP*) of 5 in the diblock copolymer was demonstrated (71% *DP*=5, $DP_{n\text{-}avg}$=5.1 by MALDI). Utilizing CD, IR, DLS, and SEM a mechanism is described where *in situ* β-sheet co-assembly of both co-products during polymerization leads to co-precipitation providing a means to prevent peptide hydrolysis, pull the polymerization equilibrium forward, and allow for *DP* and dispersity control. This study provides a foundation to use *in situ* co-assembly to form a variety or peptide-polymer diblocks with controlled *DP* and dispersity.